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by AKADEMIYA2063

Annual Trends and Outlook Report 2024

ADVANCING THE CLIMATE AND BIOECONOMY AGENDA IN AFRICA FOR RESILIENT AND SUSTAINABLE AGRIFOOD SYSTEMS

Edited by
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About ReSAKSS | *www.resakss.org*

Established in 2006 under the Comprehensive Africa Agriculture Development Programme (CAADP), the Regional Strategic Analysis and Knowledge Support System (ReSAKSS) supports efforts to promote evidence- and outcome-based policy planning and implementation. In particular, ReSAKSS provides data and related analytical and knowledge products to facilitate CAADP benchmarking, review, and mutual learning processes. AKADEMIYA2063 leads the work of ReSAKSS in partnership with the African Union Commission, the African Union Development Agency-NEPAD (AUDA-NEPAD), and leading regional economic communities (RECs). AKADEMIYA2063's mission is to provide data, policy analysis, and capacity strengthening support to enable African Union (AU) Member States to achieve economic transformation and shared prosperity in support of AU's Agenda 2063.

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ReSAKSS

Annual Trends and Outlook Report

2024

Contents

Contents *Continued*

List of Tables

List of Figures

Figures *Continued*

Figures *Continued*

List of Boxes

Abbreviations

AATS	Africa Agriculture Transformation Scorecard
ACCF	Africa Climate Change Fund
ACFTA	African Continental Free Trade Agreement
AfDB	African Development Bank
AFOLU	Agriculture, forestry, and other land use
APEC	Asia-Pacific Economic Cooperation
ATOR	Annual Trends and Outlook Report
AU	African Union
AUC	African Union Commission
AUDA-NEPAD	African Union Development Agency—New Partnership for Africa's Development
BR	Biennial Review
CAADP	Comprehensive African Agriculture Development Programme
CEN-SAD	Community of Sahel-Saharan States
COMESA	Common Market for Eastern and Southern Africa
COP	Conference of Parties
CPA	Consolidated Plan of Action
CPI	Climate Policy Initiative
CSA	Climate-smart agriculture
EAC	East African Community
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
ESA	European Space Agency
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FOLU	Food and Land Use Coalition
GCF	Green Climate Fund
GDP	gross domestic product
GHGs	Greenhouse gases
GPG	Good Practice Guidance
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority on Development
IPCC	Intergovernmental Panel on Climate Change
JSR	Joint Sector Review
LST	Land surface temperature
MODIS	Moderate-Resolution Imaging Spectroradiometer
MRV	Measuring, reporting, and verification
MVWSI	Modified vegetation water supply index
NAIP	national agriculture investment plan
NAPs	National adaptation plans
NARO	National Agricultural Research Organization
NDCs	Nationally determined contributions
NDVI	Normalized difference vegetation index
OECD	Organisation for Economic Co-operation and Development
REC	Regional economic community
ReSAKSS	Regional Strategic Analysis and Knowledge Support System
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SMEs	Small and medium enterprises
SSA	Africa south of the Sahara
STI	Science, technology, and innovation
TPRI	Tropical Pesticides Research Institute
TVET	Technical and Vocational Education and Training
TWG	Technical Working Groups
UMA	Arab Maghreb Union
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
WEF	World Economic Forum
WHO	World Health Organization

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Foreword

Africa stands at a pivotal moment in its development trajectory. Climate change is compounding existing and emerging challenges and threatens food security and nutrition, livelihoods, and sustainable development. The continent, rich in biodiversity and natural resources, is increasingly recognizing the potential of the bioeconomy as a driver of sustainable growth, economic diversification, social transformation, and resilience against the impacts of climate change. The concept of a bioeconomy, which integrates the sustainable use of biological resources into economic systems, offers a unique opportunity to harness Africa's ecological wealth for the benefit of its people and the planet. However, realizing this potential requires a concerted effort to build and sustain political momentum.

The political landscape in Africa is evolving in response to the urgent need for sustainable development. Across the continent, leaders are beginning to embrace the bioeconomy as a strategic priority, recognizing its alignment with continental and global development goals and agendas, including climate change, poverty alleviation, food and nutrition security, environmental sustainability, and resilience to climate change. The African Union's Agenda 2063 provides a framework to leverage the opportunities of a bioeconomy. However, translating this vision into tangible action requires robust political commitment, innovative policy frameworks, regional collaboration, and South-South exchange.

The political momentum for Africa's converging climate change and bioeconomy agenda is being fueled by several key factors. First, the growing recognition of the continent's vulnerability to climate change has underscored the need for sustainable and resilient economic models. As climate impacts become more severe, there is an increasing urgency to shift away from extractive and unsustainable practices. The bioeconomy offers a pathway to do this by promoting the use of renewable biological resources and fostering innovation in areas such as biotechnology, sustainable agriculture, and renewable energy.

Second, Africa's demographic dynamics are driving the need for economic transformation. With a rapidly growing population, there is a pressing need to create jobs, especially for youth, and to ensure food and nutrition security for all. The bioeconomy, with its potential to create new industries and value chains, offers a promising avenue for job creation and economic diversification. Political leaders across the continent are beginning to see the bioeconomy as a way to leverage Africa's comparative advantages in agriculture, forestry, and biodiversity to build a more inclusive and resilient economy.

Third, the global shift toward sustainability and the green economy is creating new opportunities for Africa to position itself as a leader in the bioeconomy. International partnerships, investment flows, and technology transfers are increasingly directed toward sustainable development pathways. This international engagement is helping to build the political momentum needed to drive bioeconomy strategies at the national and regional levels.

While political momentum for Africa's bioeconomy is undoubtedly growing, and countries are beginning to identify their own bioeconomy entry points and pathways, challenges need to be addressed. These efforts should include more coordinated policy frameworks, greater investment in research and development, and stronger institutional capacities. Additionally, there is a need to ensure that the benefits of the bioeconomy are equitably distributed, particularly among rural communities and marginalized groups.

Africa's political leaders, the private sector, and other key stakeholders need to unite to sustain and amplify the momentum for Africa's resilience and green growth agendas. The African Union climate change and resilience development strategy, the post-Malabo Comprehensive Africa Agriculture Development Programme (CAADP) agenda that will set Africa's development agenda for the coming 10 years, the implementation of countries' United Nations Food Systems Summit national pathways, and the development of the third generation of countries' nationally determined contributions (NDC 3.0), which are due to be submitted next year, all present an opportune moment for a radical shift in how the agendas for agrifood systems, climate change, and economic development are aligned. The bioeconomy offers a natural pathway for greater convergence.

However, transitioning to a resilient agrifood system and a bioeconomy will require a step-change from current economic growth approaches and political leadership, with a clear vision and the will to embrace new approaches to addressing current and emerging challenges.

The 2024 Regional Strategic Analysis and Knowledge Support System (ReSAKSS) 2024 Annual Trends and Outlook Report (ATOR), the official monitoring and evaluation report for the CAADP, recognizes the high-priority status of climate change on Africa's development agenda.

In addition to high-level political commitment, regional collaboration, South-South learning, and collaboration with partners in Europe and the United States will be crucial to enable countries to leverage their unique contexts and competitive advantages and build a more sustainable and prosperous future for all. This report presents evidence-based recommendations to harmonize and advance the food and climate change agendas. The research should be leveraged as a policy tool for decision-makers to promote dialogue on pathways toward a more comprehensive post-Malabo CAADP agenda that integrates the priorities for a successful food systems transformation toward an agriculture-led, broad-based economic transformation across Africa.

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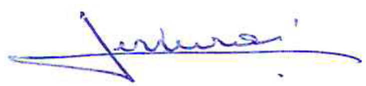

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Executive Summary

Africa is facing the brunt of the global climate crisis. Many of the continent's regions are seeing decreased agricultural productivity due to climate stresses and shifting rainfall patterns, and its coastal nations are confronting rising sea levels that threaten livelihoods and critical infrastructure. The torrential rains in Libya in September that caused the collapse of two dams and several thousand deaths, the recent floods in Kenya, and the El Niño–induced droughts in Southern Africa impacting more than 30 million people are just a few examples of how extreme weather events are becoming more frequent and more intense. Without immediate action to both mitigate greenhouse gas (GHG) emissions and adapt to climate change, there is a serious risk that millions of people across the continent will be pushed into acute hunger and lose their livelihoods, putting the economic development progress achieved over the past decades in jeopardy.

Yet, at the same time, innovations in developing a sustainable bioeconomy in Africa offer real opportunities to address multiple challenges simultaneously. The bioeconomy—the application of science, technology, and innovation to the sustainable production and use of biological resources to create innovative products, processes, and services for all economic sectors—is set to play a crucial role in fostering sustainable development by utilizing biological resources, such as plants, animals, and microorganisms, to produce food, energy, and materials. The bioeconomy promotes the shift away from fossil fuel dependency, helping to mitigate climate change while supporting biodiversity and ecosystems. By harnessing innovations in biotechnology and circular economy principles, the bioeconomy also creates new industries and jobs, fostering economic growth. It encourages efficient resource use, reduces waste, and contributes to food security, making it essential for addressing both environmental and socioeconomic challenges.

The 2024 edition of the Annual Trends and Outlook Report (ATOR) explores the challenges that the climate crisis poses for agrifood systems, and the opportunities offered by a transition to a bioeconomy to mitigate and adapt to the adverse impacts of climate change. This ATOR seeks to support the ongoing development and the subsequent implementation of a new 10-year Comprehensive Africa Agriculture Development Programme (CAADP) strategy by the African Union (AU). The chapters of this report highlight priority areas for action, ranging from developing an integrated policy approach to mitigate and reverse the negative effects of climate change to expanding investment in bioeconomy to leverage biotechnology, agricultural waste, and renewable resources and to enhance value addition and diversify income streams for farmers and rural communities. More importantly, the report highlights the win-win relationship between climate actions and expanding the bioeconomy, with lessons from the continent and beyond. It also stresses the urgency of accelerating the implementation of national, continental, and regional climate change initiatives.

The 12 substantive chapters and two featured issues of the 2024 ATOR seek to bridge the knowledge gap around climate change and bioeconomy agendas by generating new evidence and compiling existing knowledge. The chapters cover specific topics related to climate change and bioeconomy within the context of Africa's agrifood systems transformation and address a variety of issues ranging from climate change impacts and responses to the opportunities offered by the bioeconomy in African agrifood systems. Below is a summary of key findings.

Agricultural Emissions and Vulnerability to Climate Risk

The concentration of methane associated with different land uses was assessed in order to track progress in meeting commitments to reducing GHG emissions made under nationally determined contributions (NDCs) and also to support strategizing around mitigation interventions in African agrifood systems. The estimates show that methane emissions vary significantly among countries, land uses, and seasons. The results also reaffirm the significant contribution of agriculture to methane emissions in Africa and the significant variation of atmospheric methane levels across the sowing, growing, and harvesting seasons, with more pronounced methane emissions during the harvesting season.

Analysis of the agrifood system's spatial distribution of environmental risks and vulnerability to climate change reveals significant and varied incidences and exposures across the continent, highlighting several critical areas requiring immediate attention and strategic intervention. The evaluation indicates a notable increase in temperatures in some regions, particularly in southern, eastern, and parts of western Africa. This analysis also uses case studies from Rwanda and Senegal to shed light on vulnerability to climate change. The two case studies reveal that household vulnerability is largely attributable to the inability of households to adapt to climate shocks.

Economic Impacts of Climate Change

Climate change poses several threats to agrifood systems, including intensified socioeconomic crises caused by extreme weather events and a slow-down of long-term growth and less sustainability of the macroeconomy through reduced agricultural productivity, among other factors. At the macro level, climate change reduces economic growth, reportedly by about 2 to 8 percentage points; increases unemployment, mainly for unskilled labor; and exacerbates poverty and food insecurity. However, the ability of countries to prevent, anticipate, absorb, adapt, and transform rapidly in the face of climate shocks and stresses depends on their stage of agrifood systems transformation. The three types or stages of agrifood systems—traditional, transitional, and modern—are affected differently by climate change and hence require different strategies to adapt to and mitigate the adverse effects.

Similarly, the sensitivity to climate stress in terms of reduction in productivity is significantly different across agricultural commodities, indicating that redirecting agricultural development efforts toward crops that are less sensitive to shocks could be beneficial. Some crops—including maize, sorghum, and soybeans—will see either a greater productivity boost or a smaller loss in Africa than in the rest of the world. However, groundnuts and rice will fare slightly worse in Africa than in the rest of the world, and wheat and potatoes will suffer large losses that far exceed those seen at the global level.

Policy Responses to Climate Change

Almost all African countries have responded to the global call for mitigating and adapting to climate change impacts by developing strategies and action plans, including NDCs and national adaptation plans. However, these responses are not enough to reverse the adverse effects or mitigate their causes. Despite noteworthy advancements in developing climate change initiatives, African agriculture remains susceptible and insufficiently resilient to climate shocks. Moreover, climate-smart interventions such as irrigation, sustainable land management, and agricultural insurance, which have long been advocated to enhance climate adaptation, cover only a fraction of arable lands and farmers. These interventions have not yet reached the scale needed to build resilience, largely due to challenges related to insufficient climate finance, the inability to scale best practices, and ineffective climate governance systems that show little or no integration and alignment with countries' agrifood system transformation ambitions.

The energy transition has been an important instrument to mitigate climate change and enhance the resilience of rural communities. However, the transition to renewable energy as a critical strategy for addressing climate change and ensuring sustainable development is best achieved through a "just transition" that not only addresses the issue of sustainability but also ensures that affordable energy options are widely accessible and create new job opportunities. Mini-grids and other decentralized energy solutions are found to be important technical pathways for achieving a just energy transition, particularly in remote and underserved regions.

A major challenge to the effective implementation of countries' climate commitments and ambitions is a lack of climate finance, in particular the limited funds dedicated to adaptation projects and interventions. The current climate finance flows to agrifood systems fall significantly short of meeting Africa's requirements. The adaptation finance gap is particularly large when looking specifically at small-scale agrifood systems. Moreover, current climate finance flows inadequately address gender inequality and social exclusion. Given the structural, institutional, and technical barriers currently constraining the effective mobilization and deployment of climate finance for agrifood systems, it is critical to focus on the application of blended finance instruments and their potential to catalyze private investment at scale by de-risking agrifood transactions or creating more attractive risk-adjusted returns that also deliver environmental and social benefits.

Bioeconomy and New Opportunities

As a pathway to sustainable economic growth and resilience-building, the 2024 ATOR explores the opportunity afforded by integrating the bioeconomy into countries' agrifood system transformation processes and climate agendas. By fostering efficient resource use and waste reduction, a circular bioeconomy offers a promising strategy to address the complex challenges of economic growth, food security and nutrition, and sustainability in Africa.

The experiences of expanding the bioeconomy in selected African, Asian, and Latin American countries (Ghana, Namibia, Uganda, Thailand, and Brazil), as documented in this report, demonstrate the importance of elevating the bioeconomy to a top policy priority and working across sectors and in continuous dialogue with all stakeholders. These experiences suggest the importance of linking bioeconomy initiatives with entrepreneurship and innovations in bio-based sectors, partnering in international platforms and sharing knowledge with other countries and regions, and improving coherence in the bioeconomy's sustainability objectives through multilateral agreements on climate and biodiversity, among other issues. The countries studied tend to harness their natural resources and bioeconomy sustainably, albeit with different entry points aligned with their unique environmental challenges and economic structures.

There are also significant business opportunities linked to the bioeconomy, ranging from large-scale insect farming to aquaponics. However, realizing this potential fully will require concerted efforts to overcome existing barriers, particularly in terms of policy, community engagement, and technological innovation.

There are also opportunities for regional integration within the remit of regional economic communities (RECs) and also by leveraging the African Continental Free Trade Area. Given its distributive nature, a bioeconomy will incentivize micro, small, and medium enterprises and the informal sector, which together make up a large part of the African economy. However, to fully exploit the business potential of a bioeconomy, African countries need to develop bioeconomy clusters of innovation and entrepreneurial activities based on renewable biological resources and their unique needs and natural advantages.

Converging and Mainstreaming Climate Change and Bioeconomy Agendas

Opportunities associated with the expansion of the bioeconomy can help African countries build resilience against climate change and other environmental risks. However, transitioning to a bioeconomy and promoting its convergence with climate change targets and priorities requires scaling up investments in new technologies; creating a conducive environment that enables emerging companies to innovate; providing the training and education needed to drive a bioeconomy transition; and cooperation across borders, between regions, and with other continents, all while adapting to climate change.

Mainstreaming the bioeconomy in the post-Malabo CAADP agenda is a critical challenge at the continental, regional, and national levels. The continent's RECs could play a key role in advancing this integrated agenda, and the East African Community has set a good example by developing a dedicated regional bioeconomy strategy. Other regional economic blocs should do the same, with the ultimate aim of developing a continental bioeconomy strategy. Africa should harness opportunities for collaboration and partnerships globally in the advancement of its bioeconomy while considering the continent's unique needs, values, and competitive advantages.

A new global trend of environmental reporting is emerging as an additional layer of complexity, with food supply chains moving toward greater reporting of quantified environmental impacts, such as carbon footprints. The key risks to this monitoring approach include fragmented landscapes with different initiatives and reporting requirements, and a disproportionate impact on producers in low- and middle-income countries due to a lack of adequate conformity in assessment and verification. African countries need to prepare to adapt, calibrate, and institutionalize emerging environmental reporting systems that are now widely used across the globe.

Concluding Remarks

Africa is facing a set of intertwined challenges and opportunities that will shape its progress in achieving sustainable development and reaching its potential for economic growth. The 2024 ATOR calls for a systematic and well-designed strategic approach to address the challenges while tapping into the opportunities. The ongoing efforts to equip Africa with a new 10-year CAADP strategy (2026–2035) to implement the post-Malabo agenda present an opportune moment for African leaders to align the CAADP goals and ambitions with emerging initiatives such as the implementation of countries' United Nations Food Systems Summit national pathways, revision of existing NDCs in 2025, and the Global Bioeconomy Summit in October 2024, hosted for the first time in Africa.

Crucially, the continent must build capacities to translate strategic choices and agendas into actions. The ATOR tracks the progress made by African countries against CAADP indicators, finding that, of the 49 AU Member States that participated in the fourth Biennial Review in 2023, not one is on track to achieve the Malabo commitments by 2025. Concerted efforts, and a doubling down on commitments, coupled with dedicated and visionary leadership are urgently required if African countries are to meet continental and global sustainable development and climate change targets. To meet these targets, CAADP implementation capacities at the country and regional levels must be further strengthened, including through embedding national agriculture investment plans in country planning and budgeting cycles and enhancing interministerial and intercountry coordination.

CHAPTER 1

Introduction

Augustin Wambo Yamdjeu, Katrin Glatzel, Getaw Tadesse, and Moumini Savadogo

Taken together, long-term dynamics such as demographic changes, urbanization, and a continent-wide nutrition transition pose a complex set of challenges to African agrifood systems. These challenges are further compounded by the frequent and extreme weather events linked to the deepening climate crisis, whose effects range from prolonged droughts, floods, and disease outbreaks, to rising sea levels, increasing heatwaves, and changing rainfall patterns. Left unmitigated, the likely effects on agricultural yields and productivity, infrastructure, broader economic growth, and community livelihoods risk unraveling the progress made in improving food security and nutrition, as well as alleviating poverty. In one of the latest illustrations of climate change impacts across Africa, several thousand people lost their lives in Libya after torrential rain caused two dams to collapse in September 2023. The recent El Niño–induced droughts and floods across Southern Africa have led the United Nations and its partners to call for urgent action, as more than 30 million people across the region face the effects of severe drought. The consortium has warned that millions could be pushed into acute hunger unless support is urgently mobilized before the next lean season (WFP 2024). These shocks are seriously disrupting production cycles and hampering the ability of countries to guarantee food security for their populations.

While Africa only generates about 4 percent of global greenhouse gas emissions (WMO 2023), the continent is particularly vulnerable to climate change and suffers disproportionately from its effects. Africa south of the Sahara is facing the brunt of the climate crisis, with many regions seeing decreased agricultural productivity due to climate stresses and shifting rainfall patterns. At the same time, coastal nations are confronting rising sea levels that threaten livelihoods and critical infrastructure.

Africa's agrifood systems must adapt to a changing climate to ensure that they can continue to support livelihoods, generate sustainable incomes, and provide nutrition, while doing so in an environmentally sound manner (Malabo Montpellier Panel 2022a). Building adaptive capacity and resilience to climate change is therefore a top policy priority for African governments, one which requires concerted action and multistakeholder and multisectoral cooperation. These efforts must go hand-in-hand with efforts to "bend the curve," or flatten the upward trend in warming, and to adopt nature-based climate solutions for emission reductions, such as agroforestry and sustainable land and soil management. Other important actions include leveraging knowledge and biological resources to develop a sustainable bioeconomy to provide products, processes, and services that optimize social, economic, and environmental benefits and accelerate societal prosperity (Malabo Montpellier Panel 2022b). The African Union's adoption of a Climate Change and Resilient Development Strategy and Action Plan and the 2021 Green Recovery Action Plan (AUC 2022) demonstrates continent-level commitment to address the climate crisis. In the draft of the new 10-year Strategy on CAADP, which is currently in preparation, the African Union is elevating the topic even further as it seeks to build and strengthen the interlinkages between agrifood systems transformation and climate change (AUC 2024).

Last year's 28th session of the Conference of Parties (COP28) to the United Nations Framework Convention on Climate Change occurred at a critical moment, as efforts to achieve the Paris Agreement goal of limiting the rise in temperatures to 1.5 degrees Celsius above pre-industrial levels failed to yield expected results. As COP28 kicked off, global CO2 emissions from fossil fuels were expected to grow 1.1 percent in 2023. Recent findings suggest that emissions have effectively grown on average 0.5 percent a year over the last 10 years, with 2023 likely to be the peak (Climate Analytics 2023).

Within the context of climate change and the need to preserve the natural resource base and biodiversity upon which African economies and livelihoods depend, the bioeconomy presents a promising avenue for sustainable development in Africa. Innovations in developing a sustainable bioeconomy in Africa offer real opportunities to address multiple challenges simultaneously. As reported by Aidoo and colleagues (2023), the overlapping and interlinked challenges of food systems, and their heterogeneity, mean there is no "silver bullet" to improve their sustainability. However, among feasible solutions, the bioeconomy has been noted as a pivotal trajectory for enhancing the food system's productivity potential and delivering sustainable products and services (Gatune, Ozor, and Oriama 2021; Nyarko et al. 2021). The narrative around the bioeconomy has evolved, with the current metadiscourse positioning it as a growth pattern that applies science, technology, and innovation to the sustainable production and use of biological resources to create innovative products, processes, and services for all economic sectors (Kruger et al. 2020; Global Bioeconomy Summit 2020; Bugge et al.2016).

This 2024 edition of the Annual Trends and Outlook Report (ATOR) thus seeks to clarify the convergence between the climate change and bioeconomy agendas in the context of the post-Malabo CAADP agenda. It provides an overview of the latest data and analytics needed for better-informed programmatic instruments for sustainable climate-centered interventions, and for those seeking to harness the potential of the bioeconomy as a new paradigm to sustainably transform agrifood systems in Africa. There is growing recognition of the importance of sustainable biological processes and products among emerging and advanced economies. As such, the 2024 edition of the ATOR addresses the pressing question of how Africa's agrifood systems actors can be better equipped to tackle the impacts of climate change, while simultaneously reshaping and transforming economies to align with sustainability standards and nature-based solutions. Industries related to construction, food and agriculture, bioenergy, and biopharmaceuticals are significantly connected to or based on bioprocesses. The use of biomass in these industries can reduce impacts on the environment and global climate, create new and well-paid jobs, and spark further innovation. The bioeconomy thus serves as a new paradigm for addressing climate change and sustainable economic development at the same time.

This edition of ATOR focuses on the following six specific objectives:

1. Document and share research evidence and trends in adaptation and mitigation options for African agriculture;
2. Examine the impacts of climate change on agriculture and African economies, and the risks and vulnerabilities, as well as opportunities, for agrifood systems transformation;
3. Examine advances in the tracking of greenhouse gas emissions;
4. Discuss bioeconomy opportunities for African economies, including from the perspective of regional cooperation and integration to enhance the bioeconomy's potential in Africa;
5. Document and share best practices and lessons learned from bioeconomy initiatives and projects in Africa and other regions, which can be integrated into ongoing strategies that foster inclusive and equitable growth, job creation, and rural development in Africa;
6. Analyze and discuss the financing of climate change and bioeconomy agendas in Africa as a way to remove major constraints for many African countries and thus accelerate progress in climate adaptation, food safety, and other key food systems issues.

The 2024 ATOR seeks to inform the ongoing preparation of the post-Malabo CAADP agenda, led by the African Union, and to highlight the importance of aligning and harmonizing the agendas for nutrition, food, climate change, and sustainable economic development, as well as opportunities for doing so. This edition comes at a critical moment for Africa, as the continent prepares to adopt its new 10-year strategy to drive agrifood systems transformation in January 2025.

With a total of 12 thematic chapters and two featured issues, the 2024 ATOR seeks to bridge the knowledge gap around linking the climate change and bioeconomy agendas by generating new evidence and compiling existing research. It covers specific topics related to climate change and the bioeconomy within the context of African agrifood systems transformation, with chapters organized into three sections on climate change, bioeconomy, and policy actions.

Impacts of and Responses to Climate Change

The first six chapters of this year's ATOR assess trends, impacts, and responses to climate change. In Chapter 2, Wambo Yamdjeu and Glatzel describe the connection between climate change and the bioeconomy. The authors review the evolving policy landscape and propose to strengthen Africa's shared development focus by adopting a bioeconomy lens. The authors discuss the convergence of the climate change and bioeconomy agendas within the context of the post-Malabo CAADP development and provide direction for improving existing policy efforts on both key themes.

In Chapter 3, Tankari and Fofana review existing evidence on the impacts of climate change on the macroeconomy and agrifood systems, analyzing the impacts of climate change on African economies and highlighting opportunities for agrifood systems transformation. The authors describe the effects of climate change on economic growth, underemployment, and other macroeconomic indicators, and examine how the three types of agrifood systems, which include traditional, modern, and transitional systems, are affected by climate change.

In light of growing recognition that reducing methane emissions might be a more effective strategy to mitigate global warming, Faye, Dia, Dia, and Ly use satellite remote-sensing data to address the gaps in methane emissions data across African countries. Chapter 4 assesses current methane concentrations across the entire continent, explores the relationship between methane emissions and crop types cultivated, and analyzes the potential relationship between methane concentration trends across cropland and climate parameters such as temperature and rainfall. Through this comprehensive data analysis, the authors aim to identify trends, patterns, and spatial distributions of methane emissions and examine their concentrations over time and across different geographical locations and crop types to uncover critical insights into the drivers of methane emissions.

Chapter 5, authored by Yade, Dia, and Grace, addresses climate change in African agrifood systems through the lenses of environmental change, health outcomes, and household vulnerabilities. It aims to provide a comprehensive overview of how climate change influences these interconnected domains, driving home the need for integrated and adaptive strategies and painting a holistic picture of the challenges and potential pathways to resilience.

In Chapter 6, Thomas examines the likely impact of climate change on African agriculture between now and 2050 and presents a set of modeled results for the continent and the five subregions, drawing from crop and bioeconomic models that use multiple climate models as inputs. The chapter outlines the impact of climate change on the major crops for the continent and each subregion, describes the climate models used in the analysis, and presents key agricultural commodities for the continent and each subregion. Thomas also describes Africa's climate, along with changes that have been observed already, outlines crop model results for Africa, and lastly, presents the results of the bioeconomic model, which considers how climate change affects other countries, particularly the comparative advantages of Africa under climate change.

With a focus on climate adaptation options in Africa, Chapter 7 offers a detailed review and assessment of Africa's climate adaptation policies and actions in terms of the typologies of actions, state of implementation, and effectiveness. Authors Tadesse and Barry also examine key priority challenges facing African countries in the design and implementation of their adaptation plans, aiming to shed light on priority areas for policy actions and implications for the post-Malabo African agriculture development agenda. A summary of the conceptual and empirical discourses surrounding adaptation actions, with a special focus on building resilient and adaptive agriculture in Africa, is also provided.

Bioeconomy and New Opportunities

In Chapter 8, Abe-Inge, Aidoo, Kwofie, and Ulimwengu explore the potential of a nutrition-sensitive circular bioeconomy in transforming Africa's food systems, examining both the challenges and opportunities that lie ahead. Through this lens, the authors seek to provide a better understanding of how to harness the bioeconomy's principles to achieve sustainable development goals, ensuring that food systems not only support economic growth but also advance health and environmental objectives across the continent.

This edition of the ATOR takes a deep dive into a selection of country-level bioeconomy experiences in Africa, Latin America, and Southeast Asia that showcase good practices, policy innovations, key drivers, and success stories. In Chapter 9, Glatzel, Virchow, Nakitto, Niyonsenga, Babu, Srivastava, and Kashandula analyze governance structures—policies, regulations, and institutions—that form a conducive and enabling bioeconomy environment, and identify the context-specific entry points each government has taken to transition to a bioeconomy. Although all bioeconomy approaches require an overarching strategy and vision, they can range from small-scale and artisanal approaches to large, industrial-scale interventions. The key is that a bioeconomy should leverage a country or region's specific local conditions and natural competitive advantages to drive economic transformation while also providing an opportunity to positively contribute to agrifood systems transformation and catalyzing untapped potential to support both climate change mitigation and adaptation. With experiences from Africa, Asia, and Latin

America, the chapter offers a tour d'horizon of existing experiences in different political and economic settings around the world.

Following a report by the Malabo Montpellier Panel (2022) on the opportunities presented by a bioeconomy for Africa, this edition of the ATOR presents the business case for adopting the bioeconomy as a new paradigm for sustainable economic growth and development. In particular, the report looks at employment generation, opportunities for women, private sector investments, and new competitive value chains, among others. It provides an overview of major technological innovations as well as existing initiatives at the heart of promoting the bioeconomy, including bio-incubators. The role of the bioeconomy in response to shocks (such as those related to climate, markets, and health) is also assessed and discussed, with a specific focus on the bioeconomy's welfare impacts and its contributions to climate change adaptation and mitigation efforts.

The business case for the bioeconomy is highlighted by the ATOR's Featured Issue 1, authored by Ecuru and Osano, which contends that the bioeconomy would be attractive to policymakers because it poses no risk to the environment and is appealing to consumers. The authors offer a review of existing bioeconomy opportunities for African countries, while also encouraging governments to embrace this novel concept and take advantage of development solutions based on the continent's existing natural resources.

Policy Actions

Among several agendas important to agrifood systems transformation efforts in Africa are financing for climate adaptation and the just energy transition. In Chapter 10, D'Alessandro, Adeniyi, and Araba present an overview of the current state of climate finance flows to food systems in Africa, then analyze the prevailing barriers that hinder the effective mobilization and use of climate finance for food systems adaptation in Africa. The authors draw attention to the opportunities arising from a wide range of innovative financing tools and mechanisms to mobilize additional finance from both the public and the private sectors, with a focus on blended finance. Lastly, the authors offer a detailed description of the key building blocks to a conducive enabling environment for climate-related investments in agrifood systems.

This edition of the ATOR endeavors to review and explore the key regulatory changes needed to foster renewable energy in Africa, analyze green energy as an output and input of the bioeconomy, and assess and track existing channels through which transitions to renewable energy sources are taking place, including solar, biofuel, hydro, wind, and green hydrogen. Discussions on energy efficiency have been gaining prominence, including within the research community and among African policymakers, and warrant a thorough review of the adoption of energy-saving technologies and reductions in biomass consumption.

Chapter 11, authored by Khennas and Sokona, reviews the existing evidence and debates on a just energy transition and low-carbon pathways in Africa, with the purpose of prompting discussions among researchers, policymakers, and practitioners. In the chapter, the authors give an account of this topic, which is still a relatively new area of research in Africa.

In Chapter 12 on climate action and the bioeconomy transition, Ecuru, Savadogo, and Araba offer a review of bioeconomy trends and the bioeconomy's potential contribution to integrating the blue, circular, and green economies for sustainable agrifood systems. The first section focuses on key formal governance frameworks at Africa's continental, regional, and national levels relevant to climate change, food systems, and development agendas. The authors look to identify enablers and regulators that can facilitate the integrated bioeconomy, which is at the intersection of the blue, circular, and green economies. The second section focuses on the main constraints to implementing climate actions and expanding uptake of the bioeconomy, while the third section discusses implications for Africa's growth.

A thorough literature review is needed to better understand the implications for African economies of the Global Green Agenda and the European Green Deal, to which the European Union has committed to achieve climate neutrality by 2050, delivering on the commitments of the Paris Agreement (Council of the European Union 2023). This review would also help illustrate potential partnerships between Africa and other regions that are playing leading roles, take stock of ongoing negotiations and prospects for climate action and the bioeconomy in Africa, review existing continental strategies on climate change and disaster reduction, and explore conditions for developing an African bioeconomy strategy.

Deconinck's assessment of the rise of environmental impact reporting in agrifood systems bridges this knowledge gap. In Featured Issue 2 of this edition, the author draws attention to powerful long-term drivers that are increasing both the demand and supply of quantified environmental impact information in agrifood systems and the potential impacts on small producers in African countries, as well as on the emerging bioeconomy landscape.

Chapter 13, a standing feature in each edition of the ATOR, reviews Africa's progress in implementing CAADP processes and progress on the CAADP Results Framework (RF) indicators. This analysis highlights areas of strong performance that need to be sustained or accelerated, as well as areas of weak performance that require urgent attention to enable the continent to meet its Malabo Declaration agricultural transformation goals. In particular, the chapter discusses progress in the CAADP implementation process and on 27 of the 38 CAADP RF indicators for which cross-country data are available.

Building on last year's edition, titled African Food Systems Transformation and Post-Malabo Agenda (Ulimwengu, Kwofie, and Collins 2023), the 2024 ATOR could not be timelier, especially now that Africa has made the strategic move to fully embrace the agrifood system paradigm. The report provides an expanded body of knowledge and bridges the knowledge gap to inform an important effort that seeks to renew the overarching policy framework of the African Union. As of this writing, efforts by the African Union to design a new strategy to transform agrifood systems in Africa have been ongoing for nearly two years. This edition of the ATOR offers the best possible evidence and analysis to help key actors involved in the process make informed choices as they chart a new strategic direction for Africa between 2026 and 2036.

CHAPTER 2

The Converging Climate Change and Bioeconomy Agendas as a Pathway Toward Implementing the Post-Malabo CAADP Agenda

Augustin Wambo Yamdjeu and Katrin Glatzel

Introduction

In June 2014, the African heads of state and government adopted the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods. The declaration contains a set of concrete goals to be attained by 2025, known as the Comprehensive Africa Agriculture Development Programme (CAADP), which in turn functions as the main policy framework for the African Union (AU) in the agricultural sector. The declaration thus provided a new direction for a more focused approach to achieving the continent's vision for agricultural growth and transformation (AUC 2014). According to the African Union Commission (AUC) and the African Union Development Agency (AUDA-NEPAD), the CAADP was designed as a practical instrument and framework through which Africa was going to drive efforts to achieve the Millennium Development Goals. The importance of evidence to inform policy design and implementation, inclusive participation of multiple stakeholder groups at all stages of the policy process, and mutual accountability for actions and results are at the heart of the CAADP. These principles help formulate high-quality policies and ensure that successful policies are scaled up while unsuccessful ones are adjusted. Since the adoption of the Malabo Declaration, 10 years have elapsed, and considerable progress toward achieving some of its targets is visible across the continent. With the lifespan of the Malabo Declaration coming to an end, the AU proactively initiated the design of a new 10-year strategy, covering the period from 2026 to 2035. As Africa has embarked on designing this successor strategy, it faces multiple complex challenges compounded by the climate crisis. With the opportune timing of this Annual Trends and Outlook Report, this chapter explores how the convergence of the climate change agenda and the transition to a bioeconomy will shape future strategic political decisions across the continent, effecting an equitable and sustainable transformation of agrifood systems. Thus, the bioeconomy can be a solution to future challenges resulting from climate change (for example, climate adaption) vis-à-vis the challenges of avoiding the unsustainable use of natural resources (through climate mitigation, land use change, and the sustainable use of inputs). Simultaneously, the bioeconomy will generate opportunities for new markets—including markets for bioproducts, bioenergy or food based on insects or waste, and carbon engineering (markets that are discussed in Featured Issue 1).

Existing Continental and Global Policy Frameworks Shaping Africa's Climate and Bioeconomy Policies

Several continental policy frameworks in Africa have already provided a basis for the development of sustainable bioeconomies. For example, a number of objectives and targets under the current Malabo Declaration commitments and the AU Agenda 2063 (Box 2.1) support the development of a bioeconomy, as they include frameworks for increasing biomass production and improving value addition across bio-based value webs, as well as for strengthening national science, research, and innovation capacities. In addition, strategies for energy, mining, industrialization, climate change, and trade have the potential to accelerate the transition to a bio-based economy. At the same time, a bioeconomy can also enable governments to meet their global commitments, including those made under the Sustainable Development Goals, national pathways under the United Nations Forum on Sustainability Standards, and climate commitments anchored in countries' national adaptation plans and nationally determined contributions. Moreover, there is an opportunity for African countries to connect with and learn from the bioeconomy strategies of and experiences in other regions, such as the European Union or countries in Latin America and Asia..

As African countries are in the process of defining the post-Malabo CAADP agenda, this is an opportune time to reassess how a bioeconomy would be anchored within the continent's development agenda and to design pathways that align the agenda's ambitions with the envisaged transition to a bioeconomy.

In the energy sector, there is a clear political commitment at the continent level to achieving a bioeconomy, as reflected in the Africa Bioenergy Policy Framework and Guidelines, a joint effort by the AUC and the United Nations Economic Commission for Africa (AUC and UNECA 2013). While this framework is primarily aimed at the country level, principles and guidelines are also provided for regional economic communities (RECs) to guide their regional policies and regulations for promoting a sustainable bioenergy sector. The policy framework seeks to address the increasing and fluctuating costs of fossil fuels at the global level as well as environmental degradation, while aiming to reduce the use of biomass (mainly in the form of charcoal, firewood, crop residues, and manure) for cooking. On the other hand, advanced bioenergy solutions such as briquettes, biochar, and biogas offer opportunities to replace petroleum-based

BOX 2.1—AFRICAN UNION AGENDA 2063

Several goals under Aspiration 1 of the African Union (AU) Agenda 2063 (a prosperous Africa based on inclusive growth and sustainable development) provide an impetus for the development of a bioeconomy. The second goal within Aspiration 1 promotes the development of education and skills, particularly in science, technology, and innovation. To meet this aspiration, the AU adopted the Science, Technology and Innovation Strategy for Africa 2024 (STISA-2024). The 10-year strategy aims to transform Africa into a knowledge-based and innovation-led society through the promotion of human capital development, innovation, value addition, industrialization, and entrepreneurship. STISA-2024 identifies food security, nutrition, and the eradication of hunger as the top 3 of its 10 priority areas, ranked in terms of their ability to benefit from the increased application of science, technology, and innovation. The strategy highlights the elements of agricultural value chains that would benefit most from a transition to a bio-based economy as (1) research and innovation in cultivation methods, seeds, soil, and climate change; (2) value addition and food transformation; and (3) infrastructure and techniques for distribution.

To these ends, STISA-2024 calls upon AU Member States to upgrade their science, technology, and innovation infrastructure; to expand the availability of quality postgraduate education, including technical and vocational education and training; to strengthen the environment for innovation and entrepreneurship; and to introduce appropriate policies for national science, technology, and innovation programs. STISA-2024 emphasizes the need for African governments to allocate at least 1 percent of their countries' gross domestic product to research and development. It is thus an important enabler of Africa's advancement in the development of bio-based economies.

Aspiration 1 includes the goal of modernizing agriculture and promoting the sustainable use of biological resources on the continent under the heading "Environmentally Sustainable and Climate-Resilient Economies and Communities." This goal urges Member States to manage their natural resources sustainably, conserve biodiversity, foster sustainable consumption and production patterns, improve water security, strengthen climate resilience and natural disaster preparedness and prevention, and expand the provision of renewable energy. To achieve these objectives, African governments and the African Union Commission are implementing the Green Recovery Action Plan, with five priorities including to "embolden nature-based solutions and focus on biodiversity through work on sustainable land management, forestry, oceans and ecotourism" (Malabo Montpellier Panel 2022, 7X).

products, reduce pollution, and contribute to rural development. The continent-level bioenergy policy framework emphasizes regional coordination of the production, trade, and use of bioenergy, including the harmonization of policies that facilitate the development of a viable modern bioenergy sector led by RECs.

Moreover, in order to harness science and technology for the socioeconomic transformation of the continent and to elevate its role in the world economy, African leaders adopted Africa's Science and Technology Consolidated Plan of Action (CPA) in 2005. Countries are encouraged to align their national policies on science, technology, and innovation with this plan. One of the flagship programs of the CPA is the African Biosciences Initiative (ABI), which focuses on research and development (R&D) in biotechnology, biodiversity, Indigenous knowledge systems, and technology development. Its strategic objectives are to develop new biosciences to protect the environment and conserve biodiversity, to build and strengthen human capacity for biosciences, to promote access to affordable and world-class research facilities, and to harness Indigenous technology and knowledge for wealth generation and the sustainable use of natural resources. ABI feeds into the agricultural, environmental, and health strategies of the New Partnership for Africa's Development (NEPAD) and is implemented through four regional bioscience networks: the Southern Africa Network for Biosciences (SANBio), the Biosciences Eastern and Central Africa Network (BecANet), the West Africa Biosciences Network (WABNet), and the North Africa Biosciences Network (NABNet). A good example of regional integration of bioeconomies, these networks comprise institutions and laboratories that have agreed to share their infrastructure and human resources for R&D at the regional level.

While the development of the continent's next 10-year agrifood systems transformation agenda is ongoing, African countries are now at a crossroads: as shown above, the foundations for national and regional bioeconomy development have been laid, and some African countries are already jumpstarting a bioeconomy transition. As the following section will show, integrating the combined ambitions of increasing climate resilience and promoting a bioeconomy into the post-Malabo CAADP agenda can support a sustainable agrifood systems transformation, one that will sustainably deliver improved nutrition outcomes.

Integrating Climate and Bioeconomy Ambitions into the Post-Malabo CAADP Agenda

The fifth commitment under the Malabo Declaration calls for improving households' resilience to climate- and weather-related risks and other shocks. While shocks were relatively uncommon in the past, in recent times their frequency and intensity have increased, with multiple crises becoming protracted and compounded. In addition to climate shocks, conflicts, health shocks, and economic shocks are frequent, complex, and large in scale (Badiane 2023; UNECA 2023). As a departure point, a recent AU assessment of African performance in agriculture transformation reported that, after two decades of implementing the CAADP, the continent has made enormous progress in economic and agricultural growth, improvement in poverty and nutrition outcomes, expansion of agricultural trade, and public investments in agriculture (AUC and AUDA-NEPAD 2023). In the same source, CAADP is credited with having raised the profile of agriculture and encouraged greater focus on the sector in terms of policy and investment, with strong linkages to overall economic growth. As Wambo Yamdjeu and Diop have recently reported (2024), upon request of the AU, AKADEMIYA2063 has, since September 2023, endeavored to take steps to help with the mobilization of expertise to assist in developing the technical content of the new strategy.

The recent work by AKADEMIYA2063 consisted of a thorough review of the commitment areas under the current Malabo Declaration to assess their continued relevance, weaknesses, and strengths. It also involved exploring opportunities to fill gaps, eliminate redundancies, and expand the CAADP agenda as necessary to meet the challenges and achieve the ambitions of its next 10 years while building on key lessons from the past two decades of CAADP implementation. This review was necessary to ensure that the suggested adjustments under the post-Malabo agenda are informed by evidence from the four cycles of the Biennial Review, including the indicators' number and relevance, opportunities to redirect some of them, and the challenges encountered in calculating proposed new indicators (Wambo Yamdjeu and Diop 2024). The ongoing process is anticipated to culminate in the adoption of the next declaration by the time of the AU Extraordinary Summit, scheduled to be held in Kampala, Uganda, in early 2025.

The Post-Malabo Caadp Agenda: A Preliminary Account of Efforts to Embrace an Agrifood System Paradigm and Set New Ambitions

With technical backstopping from AKADEMIYA2063, the AU outlined key modalities that would facilitate the mobilization and deployment of technical expertise to help provide needed data, analysis, and evidence to support a high-quality post-Malabo CAADP agenda. To that effect, an operational model consisting of two work streams was set up: (1) a stakeholder engagement and dialogue workstream, and (2) a data and analytics work stream. These work streams operated concurrently, with a strong symbiotic relationship and the common goal of helping deliver a new strategy and action plan for agrifood systems transformation in Africa (for the years 2025–2036) (AUC and AUDA-NEPAD 2023).

Under the data and analytics work stream, 13 technical working groups (TWGs) were identified and assigned to (1) thoroughly examine each of the Malabo Declaration commitment areas to assess any necessary changes and expansions, (2) identify the topical issues as well as emerging challenges, (3) identify opportunities to deepen and strengthen these areas while addressing challenges, (4) propose ambitions for the next 10 years, and (5) identify potential indicators and targets to measure progress. With overall facilitation from AKADEMIYA2063, individual TWGs were convened by and composed of representatives from leading African centers of expertise, research and academic institutions, technical development agencies, and global partners.

On the paradigm of embracing agrifood systems, TWG 1, focused on "principles and values of the CAADP process (from narrow agriculture-led growth to agrifood systems)" (AUC, AUDA-NEPAD, and AKADEMIYA2063 2024, 3), was convened by the University of Ibadan (Ibadan, Nigeria), the AU Commission, and the United Nations Special Adviser on Africa. The AU adopted the African Common Position on Food Systems during the 2021 United Nations Food

Systems Summit (AUC 2021), signaling a deliberate and clear shift of paradigm from the agriculture-led growth that had been the main mantra of CAADP under the Malabo round to a movement to embrace an agrifood systems approach. With this shift in the background, the group that assessed Malabo Commitment 1, "recommitment to the principles and values of the CAADP process," (AUC, AUDA-NEPAD, and AKADEMIYA2063 2024, 3) as per the scope of work described above (Olayide et al. 2024).

This TWG report stressed that agrifood systems transformation would provide (1) clear goals and much-needed direction for national plans, international cooperation, and private investments; (2) a basis for an African roadmap for implementation; (3) a framework for the accountability of African governments, donors, and the private sector for delivering results toward food systems transformation; and (4) actionable efforts on the ground to build on successful experiences and leverage the appropriate innovation and technology, including those from research and academic institutions in Africa. As the agrifood systems approach was consistent with the African Common Position in the 2021 United Nations Food Systems Summit, the submission by the TWG was to serve as the main reference document and departure point to inform strategic orientation and develop the AU's new 10-year strategy on CAADP. By embracing this transition, as presented in Chapter 13 ("Climate Action and Bioeconomy Transition: Mainstreaming Environmental Sustainability in the Post-Malabo CAADP Agenda"), Africa is demonstrating its awareness of the complexities of the dynamics at play—whereby economics, agricultural development, and nutrition intersect—while being mindful of the urgency of integrating the relevant policies promoting sustainability across sectors.

TWG 10 focused on generating the new theory of change and results framework (RF) that are necessary to shape the new 10-year post-Malabo strategy. The theory of change provides a detailed roadmap for transforming Africa's agrifood systems, one well aligned with bioeconomy goals in order to leverage biotechnology, promote circular economies, support innovation, strengthen value chains, integrate supportive policies, and build capacity. The post-Malabo RF builds on the CAADP RF applied to the Malabo Declaration (AUC/NPCA 2015). It also considers other CAADP-related strategic frameworks, which outline the essential steps and logical cause-effect relationships among activities, intermediate results, and outcomes. (Ulimwengu et al. 2024). Taking advantage of such synergy helps foster sustainable growth, environmental conservation, and enhanced food security across the continent. While this strategy addresses critical challenges and leverages opportunities, it also aims to ensure sustainable, resilient, and inclusive agrifood systems that will contribute to the continent's long-term development and prosperity.

As for the TWG 7 on enhancing the resilience of livelihoods and agrifood systems to shocks, recommended (Mbow et. 2024) that the future Kampala Declaration acknowledge the importance of building the resilience of agrifood systems in the face of multiple shocks and stresses, as well as the interconnectedness of such shocks and their implications for the following:

1. Food and nutrition security: At the household and community level, multiple shocks—such as climate change, economic disruptions, health shocks, and conflicts—severely impact food and nutrition security.
2. Ecosystem services and landscape restoration: Improving ecosystem services is crucial for sustainable development. Restoring degraded landscapes and soil health, as well as rehabilitating water sources and rainwater management systems, are vital steps.
3. Health and robustness of agrifood systems: The health and robustness of countries' agrifood systems are critical for economic stability and food security. Shocks like pandemics and trade disruptions can cripple agrifood systems, leading to shortages and price spikes.
4. Overall economic resilience of Member States: Building the overall economic resilience of Member States requires a holistic approach, which includes developing adaptive strategies to manage climate risks, investing in infrastructure to withstand shocks, and fostering social and economic policies that promote equity and inclusion.

It is worth recalling that, 10 years ago, CAADP and the subsequent Malabo Declaration set out targets to stimulate agricultural growth across the continent. Targets were defined for finance, productivity, research, and sustainability within Africa's agricultural sector, all of which, directly and indirectly, can advance a bio-based transition, as presented by the Malabo Montpellier Panel report titled Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy (2022). For instance, the Malabo Declaration commits African governments to double their agricultural productivity from 2014 levels by 2025, thereby ensuring that more biomass—a primary input for the bioeconomy—is available to drive the bioeconomy's growth. The target further promotes agro-processing—also a key factor in a thriving bioeconomy. Supported by an increase in access to financing and by investment in research, the CAADP/Malabo Declaration commitments reinforce the basis for a growing bioeconomy. In this way, the report by TWG7 concluded that the inclusion of targets on sustainability—specifically in land management and water use—will also help ensure that the transition to a bio-based economy preserves the environment and enhances resilience.

The Bioeconomy: An Emerging Integrated Policy Agenda in Africa

The complexity of agrifood systems transformation—with multiple, interlinked challenges spanning different sectors and stakeholder groups, coupled with multiple global and continental policy agendas that countries are required to implement—calls for a new paradigm in addressing these challenges while leveraging the opportunities available. While not a silver bullet, a focus on bioeconomy development provides an agenda to enhance the agrifood system's productivity potential on the continent while simultaneously delivering sustainable products and services, providing healthy diets, and creating important employment opportunities (Aidoo et al. 2023). Bioeconomy was defined by the Global Bioeconomy Summit as "the application of science, technology, and innovation" to the sustainable production and use of biological resources to create innovative products, processes, and services for all economic sectors" (GBS 2020).

A bioeconomy can help African countries progress to more sustainable production and consumption practices, in addition to accelerating progress in their continental and global development commitments and climate targets. The adoption of a bioeconomy approach can hence contribute to food security and improved health and nutrition outcomes (see Chapter 8), accelerate the just energy transition (see Chapter 11), and contribute to sustainable economic and social growth. In fact, it could enable strategic policies and initiatives to align Africa's agrifood systems transformation with local and global sustainable development commitments and the green growth agenda (Aidoo et al. 2023). The use of renewable biological resources, primarily from the agricultural sector, therefore provides a platform from which to accelerate a global transition toward greater sustainability and resilience.

The Potential of a Bioeconomy Strategy to Contribute to Climate Change Adaptation and Mitigation

The transition to a bioeconomy puts countries on the path toward more sustainable use of inputs—including natural resources such as land, water, air, minerals, forests, fisheries, and wild flora and fauna—through more efficient production and processing practices and the reduction of input demand, while providing new sources of nutrients for people from biomass products. A central principle of the bioeconomy is the efficient use of natural resources and the circularity of production through the recycling and reuse of waste (Malabo Montpellier Panel 2022). The opportunities to develop new value-added products from biomass and waste, especially agricultural waste, offer some of the most noteworthy prospects for developing a bioeconomy and for doing so at scale. The application of cutting-edge bioscience and biotechnology to reuse and transform waste from agro-processing and other value-adding sectors and value chains such as livestock, coffee, cotton, wood, sisal fiber, and fruits offers clear entry points for Africa's bioeconomy development and is strongly aligned with countries' commitments to meeting international climate targets. As shown throughout this report, there are multiple examples from across the continent of industries in which this potential is already being harnessed. Moreover, biomaterial innovations present new employment opportunities in rural regions that continue to rely heavily on agriculture for income.

The growing demand for biomass also offers opportunities to mitigate and adapt to climate change and opens a pathway that would enable the agricultural sector to be decoupled from environmental degradation and resource depletion, in some cases achieving these goals simultaneously. Currently, several global mitigation scenarios rely on large emissions reductions across the agriculture, forestry, and other land use sectors and, at the same time, reforestation/afforestation and biomass use in a multitude of applications. Among these scenarios, the transition to a low-carbon, fossil fuel–free global economy is expected to depend extensively on bioenergy. Low-efficiency traditional biomass already forms a large source of energy for cooking, lighting, and heating across Africa. However, such energy sources present serious negative impacts on health and living conditions, particularly for women and girls who in many countries continue to be the ones primarily responsible for cooking and spend more time in the house. High-efficiency, modern bioenergy can play an important role in providing sustainable, "green" energy to nearly 73 percent of the continent's residents who live off the grid and, in turn, in improving local air conditions and reducing the pressure on Africa's forests. In 2015, a study explored the potential of biogas production in Ethiopia using by-products from coffee processing, including husks, pulp, and mucilage. The findings showed that the anaerobic digestion of these products could generate as much as 238,000 megawatt hours (MWh) of electricity and 273,000 MWh of thermal energy. The coffee processing facilities could then use this energy, leading to cost savings and reduced greenhouse gas emissions (Chala et al. 2018).

Another example is a programmatic partnership facilitated by BioInnovate Africa that brings together scientists, researchers, innovators, and entrepreneurs in Kenya, Tanzania, and Uganda to develop new fuels for rural households from food waste (BioInnovate Africa 2019). The project looks to commercialize a fuel that offers a more environmentally friendly alternative to charcoal, paraffin, and firewood to meet household energy needs, while also reducing the reliance on imported petroleum-based products and deforestation for fuelwood. Using eggshells and fruit waste (mango, banana, watermelon, orange, and papaya sugars and peels), project scientists developed a bio-alkanol gel that burns without smoke or soot and can be used as a cooking fuel using existing infrastructure. Academic and business institutions from the three countries—including Maseno University and Lake Basin Development Authority, both in Kenya; the Tropical Pesticides Research Institute, Tanzania; and the National Agricultural Research Organization, Uganda—collaborated in identifying and developing the new technological product and have established a production facility for its commercial expansion (UNOSSC 2020).

There is also significant potential in combining restorative agriculture and forestry with bioenergy and other bioeconomy programs to sequester emissions and help protect and conserve biodiversity. For example, the greater adoption of locally adapted agroecological techniques such as agroforestry can restore biodiversity in agricultural landscapes. Meanwhile, increasing soil fertility by enhancing the accumulation of organic matter from decaying plant residues reduces overreliance on chemical fertilizers and pesticides. Climate-smart agriculture and forestry approaches can offer co-benefits in food security, livelihoods, biodiversity, and health. Tree plantations, such as the Acacia senegal plantations producing gum arabic in eastern Africa, the rubber and teak plantations in West Africa, and the eucalyptus plantations of South Africa, can be a source of pulp, timber, and fuelwood, thereby relieving pressure on primary and protected natural forests (Malabo Montpellier Panel 2022). The use of timber products in construction and industry can also mitigate emissions from steel and cement production.

Moreover, combining agroforestry with livestock farming fosters the adoption of circular agriculture, in which external inputs are minimized and the environmental impact is thus reduced. Many smallholder farmers raise livestock and then use crop residue biomass as animal fodder, which reduces the available soil cover; if trees are grown on farms, however, there is more available biomass to meet livestock needs and thus to maintain constant soil cover and productivity (Helgason, Iversen, and Julca 2021). Hence, the expansion of Africa's bioeconomy can provide several possibilities for engaging in global efforts to address climate change and natural resource constraints.

The Bioeconomy as a Resilience-Enhancing Strategy

Despite the progress highlighted in the fourth CAADP Biennial Review Report, Africa is not fully meeting its resilience-building goals, with only two countries on track (AUC 2023). The development of a bio-based economy presents important opportunities for rural development in Africa. If adopted with the principles of inclusivity, sustainability, and accountability at its core, a bioeconomy can significantly reduce poverty. This effect is particularly important for Africa's rural areas, where a vibrant bioeconomy can boost agricultural productivity, support the expansion of green agro-industries, and create much-needed employment opportunities in the green economy. Meanwhile, greater uptake of biotechnology can also increase food availability and raise its nutrient content, while promoting new food (and nonfood) value chains and improving food safety.

Specifically, a bioeconomy can foster employment opportunities through a transformed and expanded agro-processing sector. Such a sector, which lies at the heart of a bioeconomy, can increase the production of agro-industrial and other value-added products with potential applications in many sectors, such as pharmaceuticals, green chemicals, industrial materials, and energy (SIANI 2016). Employment opportunities are crucial in Africa: As a report by the Malabo Montpellier Panel (2024) indicates, around 60 percent of Africa's population is younger than 25 years, and more than a third is between 15 and 35 years old. In 2022, the median age across Africa was 18.8 years, compared with 35 in North America and 47 in Japan (Statista 2022). It is expected that by 2063, there will be more than 1 billion young people between 15 and 35 years old in Africa (PRB 2019), and by 2100, almost half of the world's youth will be from Africa (Rocca and Schultes 2020). Development of a bioeconomy therefore presents a crucial pathway to addressing un- and underemployment challenges and to improving the incomes and resilience of rural and urban populations.

B-BOVID Ltd., for example, is a medium-scale agricultural enterprise in Ghana. It operates a closed-system, circular palm value chain, producing palm oil for human consumption, kernel oil for industrial use (in such products as detergents, herbicides, and cosmetics), animal feed from kernel cake, organic fertilizer from waste and briquettes, and biogas from secondary waste. In addition to operating its own plantation, B-BOVID also purchases raw materials from outgrowers and provides infrastructure for smallholder farmers to produce their oil at one of two oil mills and processing factories. Farmers receive market prices for their produce, a share of the net profit, and access to training at an innovation center. With this program, B-BOVID has devised a model that adds value to palm production, including by- and co-products; it also provides a reliable market, employment opportunities, and income to smallholder farmers and contributes to reducing the environmental and climate impacts of the palm oil value web (Gomez San Juan et al. 2019).

The application of bioscience and biotechnology to the reuse and transformation of waste from agro-processing and other value-adding sectors into a range of products with greater market value can also create job opportunities. These sectors include livestock, coffee, cotton, wood, sisal fiber, and fruit, all of which are vital to the economies of several African countries. In Kenya, the start-up Mananasi Fibre applies a locally manufactured decorticator technology to tackle the challenge of repurposing pineapple plant waste. The machinery extracts fibers from the waste, providing a sustainable solution for both textile production and agriculture. Currently, Mananasi Fibre produces three types of products: raw fiber, which can be used in textiles, packaging, and papermaking; a more refined material made of softened and disentangled fiber, used in various applications including textile production; and last, the decomposed remaining parts of the plant (leaf pulp, roots, and stems). This compost is ideal for both agriculture and gardens, where it can be used as a substitute for synthetic fertilizers.

In fact, the transformation of fruit waste into fiber for use in the fashion industry has significant potential for African countries: From cotton to leather, the creation of fashion's raw materials consumes vast amounts of resources and generates significant amounts of emissions. In addition, the fashion industry generates around 20 percent of the world's wastewater, as well as large amounts of microfibers that pollute the oceans (Fleming 2019). Amid growing calls for a more ethically and environmentally responsible clothing industry, the bioeconomy offers significant opportunities. Several fashion brands and companies have already moved toward using pineapple and banana by-products that would otherwise go to waste to produce fiber. An Italian company, Orange Fiber, started producing a viscose-like material (lyocell) made from oranges and wood pulp, while other fashion designers have pioneered mushroom-based leather alternatives (Fleming 2019; Provin and de Aguiar Dutra 2021; Jayaprakash et al. 2022).

In Zambia, forest-related activities represent more than 1 million jobs in the formal and informal sectors, and they supplement or sustain the livelihoods of up to 80 percent of rural Zambian households. Tree- and forest-based biomass products can be less vulnerable to climate shocks than some horticultural crops, including fruits and vegetables. This resilience makes a forest-based bioeconomy an important source of income for the most vulnerable groups, who are seeking to diversify their incomes to cope with the impacts of socioeconomic or climate shocks. The forest-based bioeconomy can also function as a safety net during lean seasons, conflicts, or other times of hardship, such as unemployment or illness, when farmers can collect and sell fuelwood and nonwood forest products to gain additional income (FAO 2018; Jonsson et al. 2021).

In addition, edible insects are an important source of protein and can be processed into more palatable forms. After being ground into paste or powder, they can be added to otherwise low-protein foods to increase their nutritional value. Black soldier fly larvae are also being used as a supplement for animal feed. More advanced technologies that isolate and extract insect protein are also becoming more readily available. These isolated protein sources can be used to fortify food products in a consumer-acceptable form. As the uptake of edible insects for food and livestock feed increases, using agricultural by-products as feed for insect breeding could help reduce production costs. By-products—such as pomace from fruit and vegetable processing, cacao fruit remnants, or press cakes from palm oil production—are available in large quantities. They can, however, contain various indigestible components—lignin or polyphenols, for example—that need to be reduced before use (Fraunhofer Institute 2020).

A bioeconomy also offers the opportunity to promote local processing of underused crops that often have climate-resilient characteristics and are highly nutritious, thereby offering the dual benefits of providing employment, which enables wealth creation, along with addressing malnutrition challenges (see also Chapter 8). A bioeconomy can transform the African food processing sector by effectively allowing value addition to biomass, producing valuable food products in an environmentally friendly manner. The application of research and knowledge, both scientific and Indigenous, can expand conventional linear value chains into complex, interconnected value webs that reuse waste from processing to create new products. This transformation of Africa's food processing sector will create new value chains and markets in the food system.

The Bioeconomy as a Lever to Support Agrifood System Transformation Efforts

A bioeconomy has strong regional and local characteristics. Similarities in flora, fauna, and climatic and socioeconomic conditions motivate nations to identify contextually appropriate solutions (Malabo Montpellier Panel 2022). Moreover, with the increasing globalization of natural resources and the rise of governance structures that are built to manage the extraction and use of global biomass, strategic partners with differing comparative advantages can achieve the most efficient outcomes (Malabo Montpellier Panel 2022). Policies facilitating regional cooperation will be crucial in the development and scaling of Africa's bioeconomies.

Key issues hindering the growth of the bioeconomy on the African continent include a lack of dedicated policy and regulatory frameworks on bioeconomy promotion; challenges in research, development, and innovation; a lack of financing; a small (albeit growing) entrepreneurial sector; and gaps in infrastructure. Innovations in developing a sustainable bioeconomy in Africa offer real opportunities to address multiple challenges simultaneously. A report by the Malabo Montpellier Panel (2022) draws attention to various fields of innovation that are rapidly evolving worldwide, where Africa would be well positioned to create its own unique approach. There is a real opportunity for Africa to jumpstart the growth of its bioeconomy, and the report shows how learning from successful policy innovation can facilitate and expedite the design and implementation of national bioeconomy strategies.

Although most African countries are still in the early stages of developing bioeconomies, trends at the global level—in particular in Europe, India, Latin America, and Southeast Asia—indicate a move toward a bioeconomy approach. In Africa, the East African Community's bioeconomy strategy is being finalized, while in some other countries the first generation of bioeconomy strategies is being developed (see Chapter 9). African bioeconomy agendas can address practical and concrete issues and opportunities, such as broader food security, carbon farming as part of the climate agenda, clean cooking fuels, bioplastics, sustainable construction, and biopharmaceuticals.

Important lessons can be drawn from the experiences of those African countries—particularly Namibia and South Africa—at the forefront of developing and implementing their national bioeconomy strategies: their policy and institutional innovations have shifted the needle toward systemic change and transformation, making them global pioneers of bioeconomy development (see also Chapter 9).

Country Entry Points

African countries are increasingly recognizing the importance of bioeconomy strategies for the development and transformation of their economies. As a result, bioeconomy policies are emerging at national and regional levels on the continent. South Africa launched its bioeconomy strategy in 2013 to foster its transition to a knowledge-based bioeconomy by guiding bioscience research, investments in innovation, and decision-making within a high-level framework. Namibia, on the other hand, launched its bioeconomy strategy in May 2024. Ghana, Kenya, Mali, Mozambique, Nigeria, Senegal, and Uganda have all taken great leaps forward in their bioeconomy policy development by designing policies that promote activities in bioenergy and biofuel production.

In fact, Senegal has issued two bioenergy strategies, one in 2008 and another in 2012, called Lettres de Politique de Développement du Secteur de l'Energie ("The Energy Sector Development Policy Letter"). Bioprospecting policies have also been at the center of the strategies of some African countries, such as

Kenya and Mauritius, to tap into their unique biodiversity and commercialize knowledge about traditional bioresources. Other policy efforts to develop a bioeconomy at the national level include the adoption of national biotechnology strategies by eastern African countries, including Ethiopia, Kenya, Tanzania, and Uganda, while Mauritius developed a comprehensive ocean economy strategy in 2013. The development of a bioeconomy can be initiated via selected "gateway" sectors. The chosen sectors ideally align with the focus points of long-term national development plans (as well as with broader goals for food security, nutrition, and resilience), provide clear opportunities for innovation, or represent a comparative advantage or complementary approach. Chapter 9 provides a detailed overview of the bioeconomy pathways of three African countries (Ghana, Namibia, Uganda) and shares insights on the unique experiences of Brazil and Thailand in transitioning to a bioeconomy.

Conclusion

The design and subsequent implementation of the post-Malabo CAADP agenda provides an important opportunity for African leaders and their partners not only to move beyond boosting agricultural growth and transformation by embracing an agrifood systems lens but also to ensure that this transformation takes place in a sustainable way, while protecting yet leveraging the continent's vast abundance of natural resources and biodiversity.

Transitioning to a bioeconomy through investment strategies aligned with climate change targets and priorities provides a pathway for countries and the continent as a whole to move closer to meeting this ambition. Such a pathway will require scaling up investments in new technologies, creating an environment that enables emerging companies to innovate, providing the training and education needed to drive a bioeconomy transition, and facilitating cooperation across borders, between regions, and with other continents, all while adapting to climate change.

As the subsequent chapters in this report will show, much can be learned from the experiences of countries leading the bioeconomy transition across the world, as well as from the bioeconomy innovations and inventions mushrooming across Africa. Moreover, identifying the gaps and trade-offs between sustainability and economic growth, as well as between sustainability and socioeconomic development goals (such as reducing poverty and addressing malnutrition) will form an important element of public policy guidance as countries move toward updating their NDCs in 2025 and developing their bioeconomy strategies while also implementing the post-Malabo agenda. While there may be synergies and complementarity between sustainability and poverty reduction targets in the long term, there may well be negative trade-offs in the short term. Once these gaps and trade-offs have been identified, potential public policy strategies can be developed.

CHAPTER 3

The Impact of Climate Change on African Economies and Opportunities for Agrifood System Transformation

Mahamadou Tankari and Ismael Fofana

Introduction

As in the rest of the world, the climate is changing in Africa, with data showing a slightly faster warming trend than the global average of around +0.2°C per decade for the 1991–2022 period. In Africa, the average rate of change of temperature was around +0.3°C per decade between 1991 and 2022, while it was estimated at +0.2°C per decade between 1961 and 1990. In addition, all six African subregions have experienced an increase in warming over the past 60 years compared with the period before 1960. Due to global warming, Africa is observing a change in precipitation patterns, a rise in sea level, and an increase in the frequency and intensity of extreme weather events such as droughts, floods, extreme heat, and cyclones (WMO 2023). For instance, the report on the State of the Climate in Africa in 2022 (WMO 2023) showed that precipitation anomalies were above the 1991–2020 average in northeastern Africa, large parts of West Africa, the eastern Sahel region, Sudan, and parts of South Africa. In addition, several regions experienced rainfall deficits including the western part of North Africa, the Horn of Africa, portions of southern Africa, and Madagascar. Sea level rise in Africa's seven coastal regions has been similar to the global sea level average rate of increase of 3.4 millimeters (plus or minus 0.3 millimeters) per year between 1990 and 2020. In addition, extreme weather events are growing in frequency and intensity. With respect to extreme weather events including droughts, floods, extreme heat, and cyclones, data from the Emergency Event Database in Africa showed that 80 meteorological, hydrological, and climate-related hazards were reported in 2022 (WMO 2023).

Extreme weather events such as droughts, floods, extreme heat, and cyclones are negatively impacting economies and displacing communities (WMO 2023). For example, Morocco was affected by four heat waves, each lasting between five and eight days, between May and July 2022. In addition, the period from September 2021 to August 2022 was recognized as the country's driest agricultural year recorded in the last 40 years, leading to forest fires in the northern region of Morocco (Larache, Tetouan, Ouezzane, and Taza), ravaging an area of 10,000 hectares due to the effect of high temperatures. Throughout Africa, economic damages due to extreme weather events were estimated at US$8.5 billion, and more than 110 million people were directly affected by these disaster events in 2022. Drought was identified as the leading cause of death from climate hazards, while economic damages were mainly attributable to floods. These estimates could be even higher due to underreporting. Climate change poses the greatest threat to poor and highly vulnerable countries, which have contributed the least to global greenhouse gas emissions. Data show that 9 of the 10 most vulnerable African countries are south of the Sahara: Central African Republic, Chad, Democratic Republic of Congo, Eritrea, Guinea Bissau, Liberia, Niger, Sudan, and Zimbabwe (University of Notre Dame 2021). Furthermore, West Africa, East Africa, and Central Africa have been identified as global hotspots of human vulnerability to climate change by the Intergovernmental Panel on Climate Change (IPCC 2022).

Climate change affects development in Africa through several economic channels, with one of the clearest impacts being the decline in crop yields due to changes in temperature and precipitation patterns. Extreme weather events such as droughts and floods are being exacerbated by climate change, causing widespread crop failures, livestock losses, and food shortages in many African countries. Studies have shown that increased temperatures and erratic rainfall are leading to reduced agricultural productivity in countries such as Ethiopia, Kenya, Nigeria, and South Africa (Kumar 2022). In addition, climate change disrupts food supply chains, which puts agrifood systems at the center of climate policy. All these negative effects have direct and grim implications for food and nutrition security, livelihoods, and overall well-being, especially for poor and vulnerable people. These impacts are also exacerbating poverty and inequality, as agriculture is a primary source of livelihood for millions of people in Africa, especially in rural areas. Furthermore, in most African countries, climate change impacts may extend beyond agrifood systems due to the agricultural sector's importance in many African countries' economies and its interlinkages with the rest of the economy. The objective of this chapter is to analyze the impact of climate change on African economies, with an emphasis on the agrifood system and opportunities for its transformation. The chapter's methodology relies on reviewing existing evidence on the impacts of climate change on the macroeconomy and agrifood systems.

The rest of this chapter is organized as follows: the second section reviews the macroeconomic impact of climate change. It discusses the impact pathways of climate change's effects on the macroeconomy and reviews empirical evidence of these macroeconomic effects. The third section focuses on agrifood systems and climate change issues. It provides an overview of characteristics of agrifood systems and examines how climate change affects food system activities and actors. The fourth section identifies select opportunities and barriers for African food systems transformation under climate change. The conclusion summarizes the findings and describes policy implications.

Macroeconomic impacts of climate change

Impact Pathways of Climate Change on the Economy

Climate change threatens the growth of African countries due to their limited resilience against its negative impacts. Climate change can impact economies through several channels, including changes in productivity, employment, prices, and trade. Productivity changes in agrifood systems—especially at the production level—can affect the entire economy, depending on the importance of agriculture and agricultural dependence on rainfall. Changes in agricultural value added will directly affect economic growth and food supply (and hence food security). Therefore, given the dependence of GDP growth on agricultural growth in many African countries, the effect of climate change on economic growth could be significant. Quantitative evidence grounded in empirical data shows that climate change might result in lower economic growth (AfDB 2019). For instance, estimates shows that the decline in rainfall between the 1960s and 1990s in much of Africa south of the Sahara significantly contributed to reduced agricultural production and growth rates. That rainfall decline accounted for a drop of about 9–23 percent in per capita GDP in Africa south of the Sahara relative to levels without such a decrease in rainfall (Barrios 2008). Fiscal balance and government budgeting is another channel through which climate change could affect economies. Under climate change, African governments could experience increasing pressure on budgets and fiscal balances. Climate extremes could lead to increased government expenditure and a reduction in tax revenue, ultimately resulting in an increase in government debt. The negative consequences of climate change could expand further if African countries cannot invest in adequate measures to adapt to long-term changes in precipitation and temperature, or in emergency relief (AfDB 2019). Climate change can also impact employment in the wider economy, since the agrifood system is a significant employer in many African countries. For instance, in West African countries, agrifood systems generate 40 percent of regional GDP, around US$260 billion (Ghins and Zougbédé 2019). In addition, they account for most jobs: around 66 percent of total employment, or 82 million jobs, as of 2017. Of these jobs, 78 percent (64 million jobs) in West Africa are in agriculture, while 15 percent (12 million jobs) are in food marketing, and 5 percent (4 million jobs) are in food processing (SWAC and OECD 2022). Since food prices constitute a significant share of general consumer price in most African countries, changes to food prices directly affect inflation, an important macroeconomic variable.

Table 3.1 shows that agriculture represents a significant share (23–35 percent) of GDP in Ethiopia, Kenya, Rwanda, Tanzania, and Uganda. As a result, climate change could potentially have significant effects on economic growth and the macroeconomies of these countries. In addition, food and nonalcoholic beverages have considerable weight in the consumer price index of

TABLE 3.1—SHARE OF AGRICULTURE IN GDP AND FOOD WEIGHT IN FIVE EAST AFRICA REGION COUNTRIES

Country	Population in millions (2020) [% Rural]	Agriculture shares in GDP (2021)	Food and nonalcoholic beverages weight in CPI (2021)	Major exports
Ethiopia	118 (80%)	35%	54%	Coffee, cut flowers, oil seeds, chat/khat, pulses, gold
Kenya	54 (72%)	23%	33%	Tea, cut flowers, coffee spices, vegetables, trees
Rwanda	13 (82%)	27%	27%	Coffee, live bovine cattle, tea, precious metals, pearls, gold, niobium or zirconium ores and concentrates
Tanzania	60 (65%)	30%	28%	Tobacco, coffee, cotton, cashew nuts, tea and cloves, fruit nuts (majors are manufacturing, mineral, etc.)
Uganda	46 (75%)	25%	27%	Coffee, tea, cotton, oil and fish, cereals, pearls, precious stones

Source: Geda et al. (2023).

each country, which shows the significant impact of agriculture (especially food production) on inflation in the East African region.

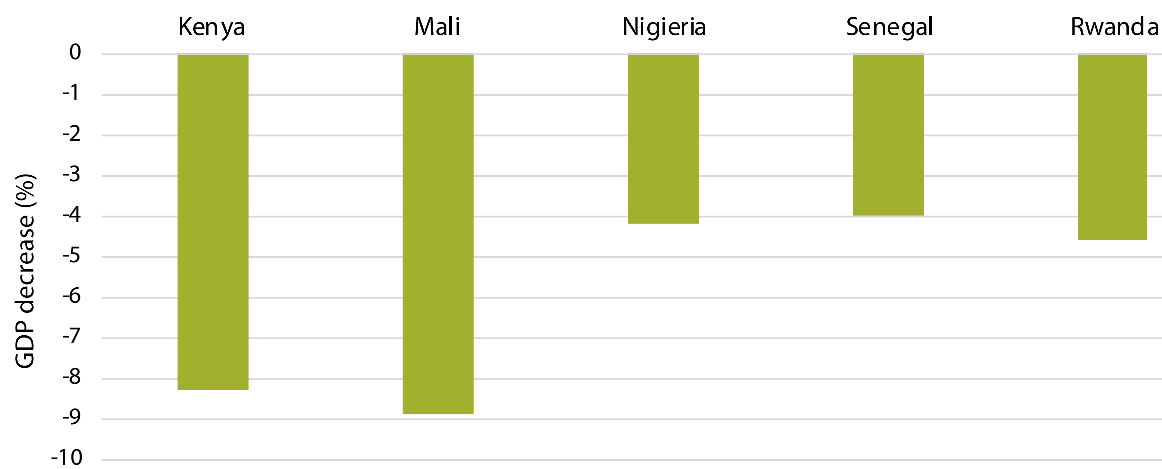
Furthermore, impacts of climate change may be channeled to economies through trade, as African countries depend on exports of agricultural commodities that are crucial to their macroeconomies. Climate change may affect their comparative advantage in the agricultural sector and therefore result in changes in the composition of trade flows as producers respond to new conditions (Mahofa 2021). A study that explored the impact of climate change on agricultural trade, particularly trade in major cereals (maize, millet, rice, sorghum, and wheat), within Africa south of the Sahara found that by the 2050s, climate change will increase most countries' need to import cereals (Mahofa 2021).

Empirical Evidence of the Macroeconomic Effects of Climate Change

The literature on economic growth generally confirms the detrimental economic impacts of climate, though to varying degrees across countries and regions depending on different indicators of climate change and economic health, as well as the existence of mitigation and adaptation policies. Estimates from AKADEMIYA2063 studies show that climate change has a potential adverse impact on GDP and other macroeconomic variables (Fofana 2023a, 2023b; Fofana and Diallo 2024; Okodua et al. 2024; Okodua et al., forthcoming). Figure 3.1 displays the GDP decrease associated with climate change in five African countries: Kenya, Mali, Nigeria, Senegal, and Rwanda. The studies used computable general equilibrium models for ex ante analysis of climate change.

The declines in GDP range from 4.0 to 8.9 percent across the five countries. In addition, the study in Kenya found that the declines in agricultural value added due to climate change have significant implications for the whole economy (Fofana 2023a). The share of agriculture, industry, and services in the Kenyan economy were estimated at 37 percent, 18 percent, and 45 percent, respectively, in 2019. Several nonagricultural industries are adversely impacted by climate change shocks in the agricultural sector through direct exposure (via forward and backward linkages) with the agricultural sector or by indirect exposure through declining overall economic performance. For instance, the chemical and petroleum product industry is also affected by climate change shocks (-6.5 percent decrease of value addition) because of its high dependency on agricultural products (47 percent of total input costs) and the high share of agricultural demand in total industry demand (39 percent). Construction value added also declines substantially (-5.1 percent) because of its dependency on forestry products (13 percent of total input costs). The contraction of the agricultural sector is primarily responsible for the shrinking GDP, contributing up to 68 percent to this decline. The industry and service sectors also contribute significantly to declining GDP (11 percent and 21 percent, respectively). Similarly, in Nigeria, the decline in GDP is mainly due to the shrinking agricultural sector, which contributes about 64 percent to the reduction in GDP, followed by the industrial sector (21 percent) and services sector (15 percent). Furthermore, the study found that the impacts of climate change on employment would disproportionately impact low-skilled laborers, with a decrease of -5.4 percent

FIGURE 3.1—GDP DECREASES ASSOCIATED WITH IMPACTS OF CLIMATE CHANGE



Source: AKADEMIYA2063 studies (Fofana 2023a, 2023b; Fofana and Diallo 2024; Okodua et al. 2024; Okodua et al. forthcoming).

in the number of jobs, compared with their medium-skilled (-4.6 percent) and high-skilled (-4.6 percent) counterparts.

In addition, a study of Cameroon using similar approach as the AKADEMIY2063 studies found that the effects of climate change are transmitted to the nonagricultural branches mainly through the intermediate consumption channel. Value added declines significantly in the health and social work sector (between -5.6 percent and -8.6 percent), the food industry (-7.4 percent and -3.6 percent), trade (-1.5 percent and -2.5 percent) and education (-1.2 percent and -2.6 percent). There is also a decline in the value added of the construction sector, which is partly explained by the fact that when household incomes fall, there is less investment in construction. Consequently, there will either be an increase or a decrease in the demand for labor in response to an increase or decrease in value added in the nonagricultural branches. However, value added improves significantly in public administration (1.1 percent and 2.0 percent), livestock and hunting (1.7 percent and 2.9 percent), and forestry (1.6 percent and 2.1 percent). In terms of employment, climate change has a negative effect on workers in formal nonagricultural sectors. Reduced production means formal firms are required to hire less-skilled and unskilled workers. Female workers are the most affected, regardless of their level of skills or the climate change scenario (for the optimistic scenario, -0.4 percent for skilled female formal workers versus -0.2 percent for skilled male formal workers, and -0.4 percent for unskilled female workers versus -0.3 percent for unskilled male workers). Formal workers who could not find work move to the informal sphere. As a result, there is an increase in informal work regardless of the level of skill. At the macroeconomic level, the simulation results reveal a -0.7 percent decline in real gross fixed capital formation and a -0.8 percent decline in real GDP (Takamgno et al. 2023).

Another study of five East African countries (Ethiopia, Kenya, Rwanda, Tanzania, and Uganda) using theoretical models from the macroeconomic and macroeconometric literature confirms that the macroeconomic effects of climate change in the region present a real threat to the economies of these five countries. Specifically, the study found that climate change negatively affects the region's economic growth (total output), agricultural output, exports, food production, and inflation. The effect of climate change on these major macroeconomic variables, which are closely watched by policymakers, has a significant impact on the region's macroeconomy. In addition, in the current and coming three decades (2020–2050), climate change could reduce total GDP and agricultural GDP by 7 percent and 11 percent, respectively. This effect, however, varies significantly across countries due to differences in vulnerability and adaptation capacity: Ethiopia could see the highest reductions in GDP and agricultural output of 14.7 and 20.5 percent, respectively. In contrast, Tanzania would see the smallest effects, with a loss of 2.5 and 3.9 percent in GDP and agricultural GDP (Geda et al. 2023).

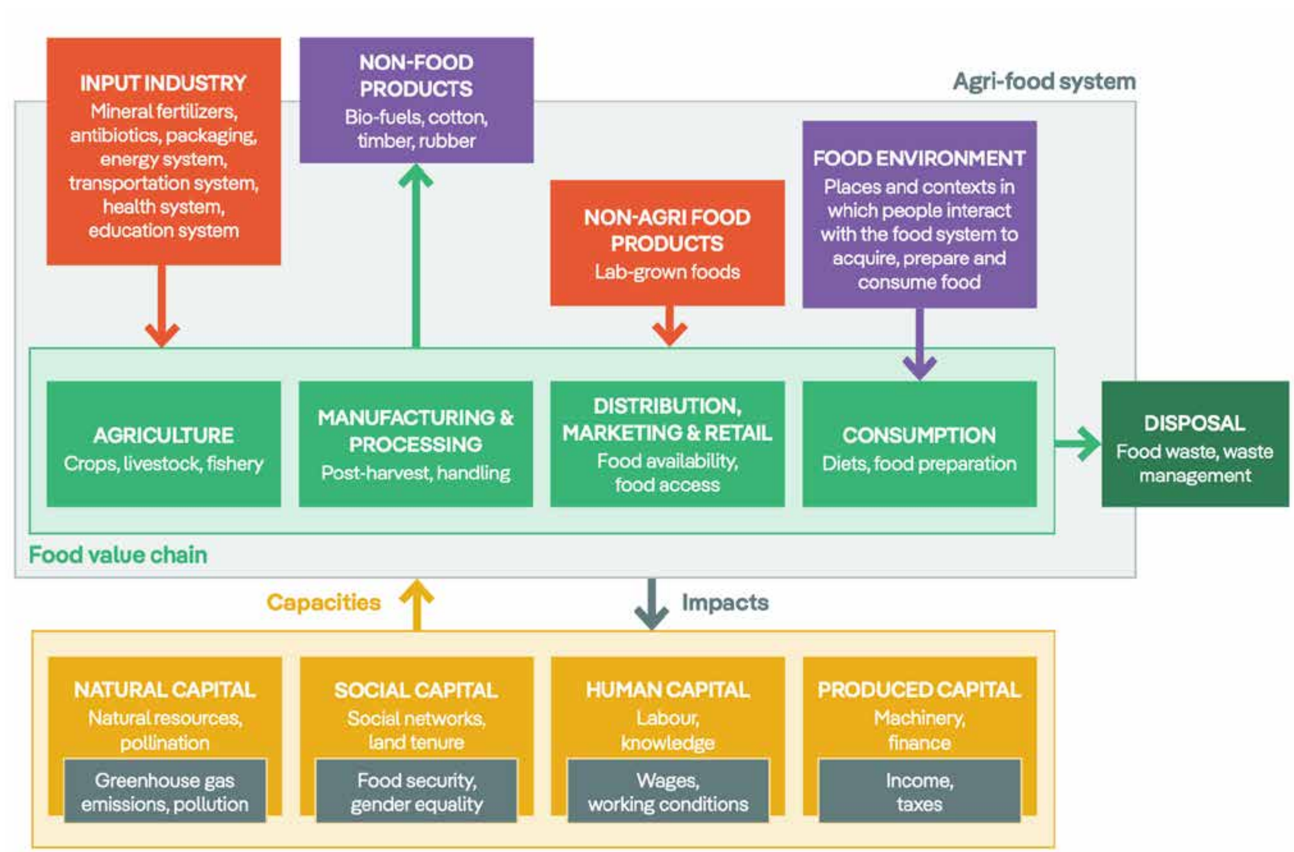
Evidence at the regional level shows that all African regions will be impacted by climate change. For instance, an African Development Bank study in 2019 on the macroeconomic effects of climate change found that negative impacts throughout all African regions would progressively compound and lead to decreasing GDP per capita. The warming scenarios entail losses by 2030 (as compared with a baseline GDP per capita scenario) that range from -0.6 percent in northern Africa in the low-warming scenario, to -3.6 percent in eastern African in the high-warming scenario (AfDB 2019).

Agrifood System Transformation and Climate Change

Characterization of Agrifood Systems

Given that climate change may severely affect agrifood systems, which are important components of economies, further understanding of these systems is needed to mitigate the macroeconomic impacts of climate change. According to the Food and Agriculture Organization of the United Nations, the agrifood system includes the entire range of actors and their interlinked value-adding activities in the primary production of food and nonfood agricultural products, as well as in food storage, aggregation, postharvest handling, transportation, processing, distribution, marketing, disposal, and consumption, as displayed in Figure 3.2 (FAO 2022). Therefore, the agrifood system is broader than the food system. The agrifood system depends on several nonfood supply chains for the purchase of inputs (such as fertilizer, pesticide, and farm and fishing equipment) and the provision of intermediate inputs to produce nonfood commodities (such as maize for biofuel production or cotton for textiles). Therefore, the key actors in agrifood systems include producers, those providing postharvest services (such as storage, transportation, food processing, food distribution and marketing [wholesale and retail]), and the final consumers, as well as input providers (FAO

FIGURE 3.2—CONCEPTUAL FRAMEWORK OF AGRIFOOD SYSTEMS



Source: FAO (2022).

2022). The contribution of the agrifood system to GDP and employment varies from one country to another. For instance, data from Ethiopia show that the agrifood system accounted for more than 48.0 percent of the country's national GDP and 77.2 percent of employment. In addition, primary agriculture alone contributed more than one-third of GDP and two-thirds of employment (Diao et al. 2023a). However, data from Zambia show that the agrifood system accounted for 15.4 percent of Zambia's national GDP and 51.1 percent of employment in 2019. Primary agriculture was only 3.1 percent of total GDP and accounted for 37.3 percent of total employment (Diao et al. 2023b).

The agrifood system and its diverse production systems are influenced by broader economic, social, and natural environments. Therefore, the agrifood system evolves as an economy undergoes transformations as part of a country's development (Diao et al. 2010). During the earliest stages of development, agriculture is dominated by subsistence farming. Following an increase in agricultural productivity, surplus production is supplied by farmers to markets, creating job opportunities for workers in the nonfarm economy both within and outside the agrifood sector (Haggblade et al. 2007). Then, demand for more diverse products is generated due to rising rural incomes, leading to more nonfarm activities such as processing, packaging, transporting, and trading. In other words, the agricultural sector drives rural—and even national—economic growth during the early stages of transformation. However, urbanization, the nonfarm economy, and nonagricultural incomes are the engine of agrifood system development, with urban and rural nonfarm consumers creating most of the demand for agricultural outputs via value chains that connect rural areas to towns and cities. In addition, the exact nature of this transformation process varies across countries because of the diverse structure of their economies and the unique growth trajectories of their various agrifood and nonfood subsectors (Diao et al. 2023a).

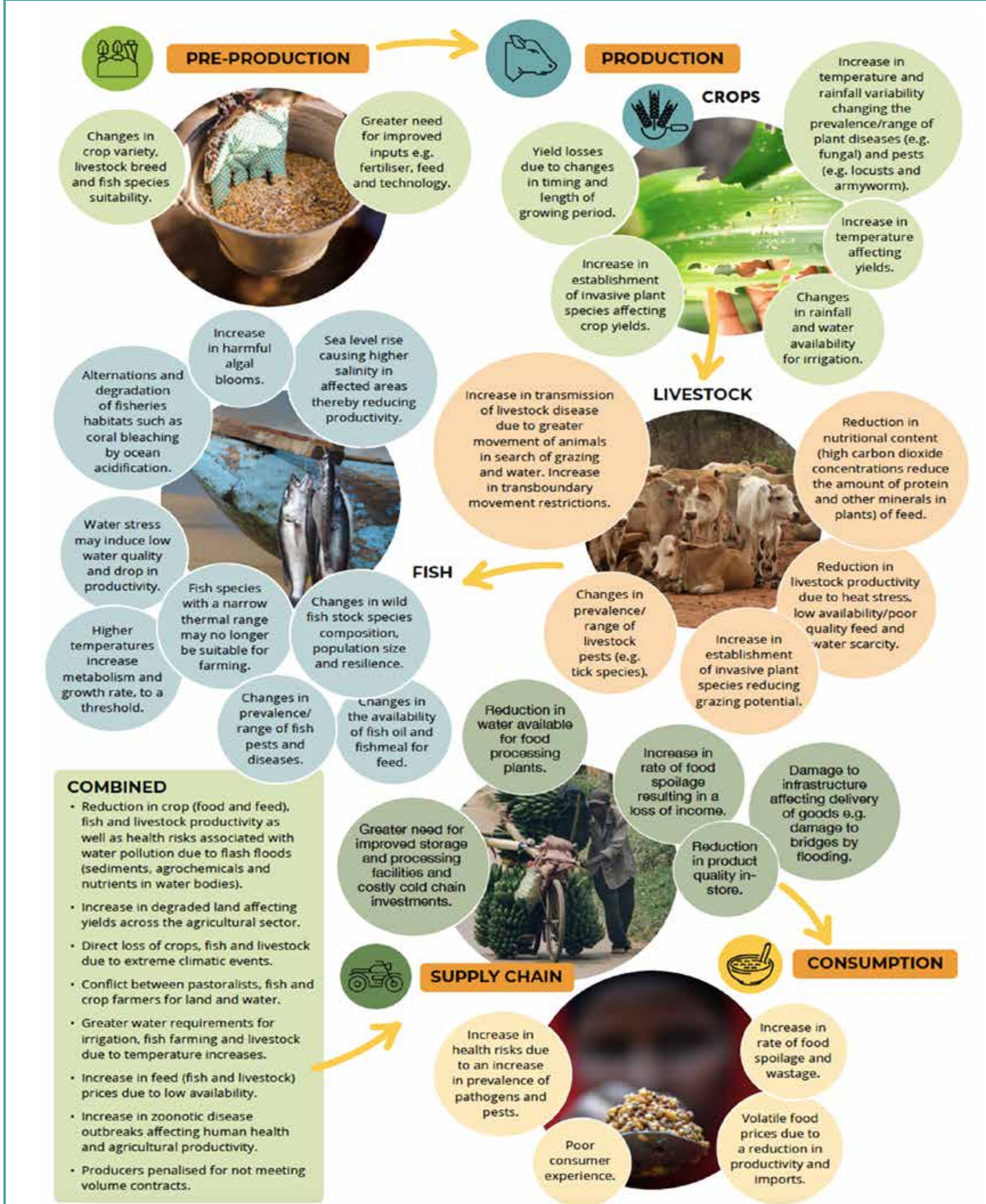
As agrifood systems gradually develop and evolve amid the transformation of economies, three stages can be identified—traditional, transitional, and modern—even though these are not distinct or clearly delineated stages, given that transformation is a continuous process. Traditional agrifood systems are mainly located in rural and coastal areas and serve local populations; modern agrifood systems focus on serving urban populations from diversified sources, including global markets; and transitional agrifood systems are in a phase of change from traditional to modern (FAO 2021). In addition, there are not only differences across countries, but agrifood systems within countries may be at different stages of development depending on location or the sectors of the economy they serve. Differences can occur in terms of structure or access to markets and services, or interactions with other systems. The ability of agrifood systems to prevent, anticipate, absorb, adapt, and transform rapidly in the face of shocks and stresses depends on their characteristics. For instance, traditional agrifood systems are vulnerable to local shocks due to their lack of adequate infrastructure and access to inputs, markets, and services such as credit and their higher vulnerability to weather conditions. The occurrence of a shock such as a flood affects the whole system, including actors, who may be severely affected by negative short- to long-term implications for food security and livelihoods. However, modern and transitional agrifood systems may be affected by the same event in different ways, depending on their scale of operations, the structure and contracting process between actors, the level of "risk-proofing" of infrastructure and capacities, and access to inputs and services such as climate risk insurance. However, modern and transitional food systems may be more vulnerable to shocks transmitted from elsewhere due to the higher interconnections and interdependences of activities and actors within them (FAO 2021).

Impact of Climate Change on Agrifood Systems

The heavy dependence on climatic, biological, physical, and chemical processes makes agrifood systems potentially vulnerable to multiple climate shocks, including extreme weather events, pest and disease outbreaks, water scarcity, and deteriorating natural resources. In addition, existing structural deficiencies such as inadequate roads, power, irrigation, clean water, processing, storage, and marketing infrastructure amplify the effects of climate shocks on agrifood systems. These deficiencies act as geographic and economic barriers that limit opportunities to develop businesses and access services, as well as creating high exposure to local weather conditions. In addition, the impacts of climate change on different components of the agrifood system vary due to the diverse characteristics of these systems, level of risk, and inherent vulnerabilities and capacities, all of which determine their susceptibility to adverse shocks and stresses. In other words, the same shock or stress may have different impacts across different components. For instance, the agricultural sector is disproportionately vulnerable to adverse climate-related events, especially droughts, floods, and storms, due to its reliance on natural processes. A study comparing climate change and business-as-usual (BaU) scenarios through the use of a computable general equilibrium model found that shocks from climate change have a significant impact on Kenya's agricultural productivity (Fofana 2023a). While BaU scenarios predict a 2.4 percent average annual increase in productivity compared with 2019 levels, climate change scenarios forecast a severe decline of 9.7 percent annually. This translates to a decline of 12.1 percent to 15.3 percent in productivity under climate change scenarios compared with BaU scenarios. All agricultural activities are affected, with fisheries and forestry being the most impacted, followed by livestock, coffee, tea, cereals (except rice), oil seeds, and vegetables. However, rice, fruit, nuts, and sugarcane exhibit lower susceptibility to climate change shocks. Another study from Mali using a similar approach also found a significant reduction in agricultural productivity due to climate change shocks. Under BaU scenarios, agricultural productivity would experience a slight increase, while climate change shocks would lead to a severe decline of 13.3 percent on average. This results in an average annual decrease of 14.2 to 16.7 percentage points in agricultural productivity under climate change scenarios compared with BaU scenarios. All agricultural activities are affected, with maize, oilseeds, fisheries, and livestock being the most impacted, followed by rice, vegetables, sugarcane, and roots and tubers. Cotton and forestry activities are less affected by climate change shocks (Fofana et al. 2023). In addition, the interlinked nature of agrifood system components means that their characteristics will determine how each is affected as the impact of a shock or stress reverberates through the system. The degree of diversity and connectivity of food distribution networks also shapes the impacts of shock events.

Figure 3.3 shows that climate change affects agrifood systems through multiple channels, and all components are likely to be affected to varying degrees (Thornton et al. 2022). At the preproduction or planning level, climate change affects the suitability of crop varieties, livestock breeds, and fish species. Therefore, there will be a greater need for improved inputs such as fertilizer, feed, and technology. At the production level, crops, livestock, and fish production are all affected. The impacts on crops include yield losses due to changes in timing and length of the growing period, as well as an increase in invasive plant species. Climate change also causes changes in rainfall and water availability for irrigation, as well as increases in temperature, which all affect yields. Estimates show that without substantial additional investment in irrigation, the share of people at risk of hunger in Africa could increase by 5 percent by 2030 and by 12 percent by 2050 due to climate change (Ringler et al. 2021). Furthermore, the increase in temperature and rainfall variability changes the prevalence or range of plant diseases (such as fungal pathogens) and pests (such as locusts and armyworm). Studies show that climate change has caused a reduction in crop yields for key staples such as maize and wheat in the tropics, and that for every 1°C increase in temperatures above historical levels, crop productivity declines by 5 percent (Challinor et al. 2014). For livestock, climate change increases the transmission of disease due to greater movement of animals in search of grazing area and water. It also changes the prevalence or range of livestock pests (such as tick species) and increases the establishment of invasive plant species, thus reducing grazing potential. Climate change also reduces livestock productivity due to heat stress, low availability or poor quality of feed, and water scarcity. With respect to the fish sector, impact pathways include sea level rise that causes higher salinity in affected areas, thereby reducing productivity. Climate change also causes an increase in harmful algal blooms, alterations, and degradation of habitats such as coral bleaching by ocean acidification. Water stress may induce low water quality and decreased productivity, while higher temperatures impact metabolism and the growth rate of fish species (for example, fish with a narrow thermal range may no longer be suitable for farming). Other potential impacts on fisheries include changes in prevalence or range of pests and diseases; in the composition, population size, and resilience of wild fish stocks; and in the availability of fish oil and fish meal for feed. At the postharvest level, climate change

FIGURE 3.3—CLIMATE CHANGE IMPACTS ON AGRIFOOD SYSTEM COMPONENTS



Source: Adapted from Thornton et al. (2022).

affects agrifood supply chains by increasing the need for improved storage and processing facilities and costly cold chain investments. It also reduces water available for food processing plants. Actors may also face an increased rate of food spoilage, resulting in a loss of income. Trade may be severely hindered by damaged infrastructure, such as roads and bridges, that affects delivery of goods. At the consumption level, climate change increases health risks due to the higher prevalence of pathogens and pests, and causes food spoilage and waste. It also can also lead to volatile food prices resulting from reductions in productivity and disruptions to trade. In addition to these sector-specific impacts, climate change has combined cross-sectoral effects, which include increases in degraded land, affecting yields across the agricultural sector; direct losses of crops, fish, and livestock due to extreme climate events; and competing demand for land and water between pastoralists and fish and crop farmers. There is also a risk of increased zoonotic disease outbreaks affecting human health and agricultural productivity (Thornton et al. 2022).

Climate change also has varied effects on actors within and between the different components of agrifood systems (FAO 2021). Understanding differences in vulnerability to various shocks and stresses, as well as the resilience capacities of agrifood systems, is necessary to identify specific measures that build resilience. For instance, at the production level, the livelihoods of small-scale agricultural producers are more likely to be adversely affected by a shock because these actors have less access to resources than large-scale producers. At the supply chain level, it is more likely that actors who are well connected to supply chains, have various sources, and deal in diverse food products will overcome supply shortages and recover from disturbances more quickly than smallholders (FAO 2021). Similarly, actors in formal markets who benefit from government regulation and programs, access to safety nets, finance, insurance, and other risk and impact mitigation mechanisms will be less affected than those in informal markets. At the consumption level, the poorest households will be more impacted by rising food prices because food represents a larger share of their household budget compared with nonpoor households. In addition, limited capacity to access credit and savings or to liquidate assets to cover deficits may worsen impacts on these households. Nutritional impacts are also possible as households reduce spending on food by shifting toward cheaper, less nutritious items, which increases vulnerability to food insecurity and malnutrition. Furthermore, declining demand for agrifood products due to shocks could potentially disturb other components of agrifood systems, ultimately affecting the flow of products. In the medium and longer term, the structure of entire systems could be affected in countries with a high proportion of vulnerable households.

Opportunities for African Food Systems Transformation Under Climate Change

Transforming African agrifood systems under climate change requires identifying and tapping into available opportunities and overcoming barriers. First, modern technologies for climate change adaptation and mitigation should be promoted in African agrifood systems for their sustainable transformation. A robust science, research, and technology system will play an important role in addressing the challenges facing Africa's agrifood systems, such as the need to improve crop and animal productivity and nutrition, tackle pests and diseases, improve storage technologies and methods, raise food safety standards, and adapt to and mitigate impacts of climate change. Despite major advances in science, technology, and engineering, current progress on these issues is not sufficient to ensure the effective transformation of agrifood systems (Hall et al. 2010). Most agricultural science, research, and innovation systems in Africa have not kept pace with developments in the sector. Despite an increasing number and diversity of actors in agrifood systems, institutional frameworks and funding have remained largely unchanged, or worse, have deteriorated (Lynam et al. 2016). To meet the current challenges facing agrifood systems under climate change, Africa's agricultural science, research, and innovation systems need to be updated. For instance, the increasing complexity of agrifood systems requires adopting an interdisciplinary and demand-driven approach in research and innovation (Horton et al. 2017). A dynamic, innovation ecosystem would foster close strategic partnerships between national agricultural research systems and private sector enterprises to scale up the production, distribution, and adoption of seeds, fertilizers, feed and fodder, new animal breeds, and locally appropriate machinery and technologies (Badiane and Collins 2020). One successful approach has been the redesign of Uganda's research system through the National Agricultural Advisory Services program. Initiated in 2001, the program rebuilt relationships from the farm level through to regional chiefs, district coordinators, and private or semi-private service delivery companies. In this way, farmers defined demand and were able to have their research and innovation needs met through a national coordination network combined with the private sector, initially at a modest cost that gradually rose to at least 50 percent of investment cost (Mbabu and Ochieng 2006). This new configuration has led to substantive positive impacts on the availability and quality of advisory services provided to farmers and the adoption and use of modern production technologies and practices, including greater use of postharvest technologies. Farmers also ventured into commercial marketing of commodities, thereby transitioning out of purely subsistence farming (Benin et al. 2007). Another example is Senegal's West Africa Agriculture Productivity Program (WAAPP), which is building a more resilient and productive agrifood system that helps mitigate climate change through climate-smart agriculture. Under WAAP, scientists have developed seven new high-yielding, early maturing, and drought-resistant varieties of sorghum and pearl millet adapted to local growing conditions. On average, the new varieties yield 1.5–2 tons per hectare—significantly more than the 0.5 ton per hectare yields that are the norm from traditional varieties. The seeds have been distributed to farming cooperatives around the country, which have been charged with producing more seeds and selling them back at a price higher than the market standard. Farmers around the country are also taught climate-smart planting techniques such as alternate wetting and drying, which raised rice productivity by 5–10 percent, reduced water use, and cut methane emissions. Greater productivity and resilience, with a concurrent reduction in fertilizer use (sustainability), is helping to deliver the triple win (World Bank 2015).

Trade is also an important driver of agrifood transformation under climate change. National and external trade, if managed carefully, can transform food systems by generating new and much-needed employment opportunities, thereby improving socioeconomic development and livelihoods across the continent ((Malabo Montpellier Panel, 2020). Increasing food demand through trade can drive specialization and intensification and thus increase productivity, supply, and incomes (UNECA et al. 2019). In addition, where trade barriers are eased, food trade can provide greater diversity in supply, potentially helping to address malnutrition, particularly undernourishment (Bonuedi 2020). Trade liberalization can also counterbalance global price fluctuations and lower domestic food prices, thereby improving access to food (Sibindi 2020). Consequently, food trade can increase resilience to shocks at the micro and macro levels and serve as an important risk management tool. A study comparing the variability of cereal production in individual countries with the average regional production volatility in the Common Market for Eastern and Southern Africa, Economic Community of West African States (ECOWAS), and Southern African Development Community (SADC) showed the potential of intraregional trade to stabilize food supplies through greater market integration. The study found that national production variability was considerably higher than regional-level variability for most countries in the three regional economic communities. The Democratic Republic of Congo and Côte d'Ivoire were the only countries experiencing lower variability in cereal production than the regional variability in SADC and ECOWAS. Moreover, in Guinea-Bissau, yearly domestic supply of cereals was 70 times more volatile than the consolidated African supply, while in Nigeria, local supply was 60 percent more volatile (Badiane et al. 2014). This suggests that both small and larger economies can gain from regional trade. Rising global temperatures, changing rainfall patterns, and more extreme weather events sparking more frequent and intense floods and droughts will continue to disrupt food production. Estimates show that without substantial additional investment in irrigation, climate change could increase the share of people at risk of hunger in Africa by 5 percent by 2030 and 12 percent by 2050 (Deason et al. 2014). The reliance of African farmers on rainfed agriculture makes them particularly vulnerable and susceptible to extreme weather events. In addition, interannual rainfall variation means that the size of local harvests can vary from year to year. Because there is considerable heterogeneity in the impacts of climate change across countries, farmers in countries that are less severely affected by particular weather outcomes may be able to sell excess supply to meet demand from consumers in more severely affected regions. Trade can thus serve as an important risk management strategy by mitigating the impact of negative shocks on domestic markets (Malabo Montpellier Panel 2020).

With climate change, access to information is more important than ever for agrifood system actors. Farmers are already battling the adverse impacts of climate change (Malabo Montpellier Panel 2019), and digital solutions that offer them access to weather information could be a game changer in transforming Africa's agrifood systems. Due to a lack of access to reliable weather information, most farmers make decisions based on traditional knowledge about the weather and seasons. Most weather stations are outdated and lack historical or up-to-date meteorological data. When farmers have access to reliable weather information and forecasts through modern weather station technology and improved weather forecasting, in combination with clear communication through mobile or online services, they can make more informed decisions about when to sow, plow, or harvest. Faster and more accurate forecasts are available through new weather technologies and prediction models. They are mainly accessible through text messaging (SMS), but also as interactive voice response (IVR) and interactive messaging services (unstructured supplementary service data, or USSD). For instance, a farmer can call and communicate with a computer to obtain the needed information through an IVR service, while a USSD service enables interactive text messaging between computer and a farmer (Malabo Montpellier Panel 2019). Some countries are making progress in gathering and sharing information with farmers. For example, Nigeria successfully launched two earth observation satellites in 2011, which are used to monitor the weather and predict and manage flood areas (Malabo Montpellier Panel 2019). In addition, Ignitia, a Swedish company, developed a tropical forecasting model with an accuracy rate of 84 percent for West Africa. The model provides daily weather forecasts to farmers in their local languages via SMS for just a few US cents per day. Farmers engaging with the service in Côte d'Ivoire, Ghana, Mali, Niger, Nigeria, and Senegal use the localized rainfall predictions to better cope with and withstand weather variabilities (Rateng 2016). Furthermore, in Ethiopia, a pilot project provided local weather forecasts, including information on temperature and rainfall, to 1,500 sesame farmers via SMS in two local languages. Ninety-six percent of farmers rated the accuracy of rainfall forecasts as being close to very accurate. With this forecast information, farmers were able to better plan when to sow, weed, apply fertilizer, and hire seasonal labor (Rateng 2016). As a result, weather information may also help to achieve higher yields under rainfed agriculture or allow farmers to extend the growing season (FAO 2018).

Another requirement for transformation is the establishment of social protection programs to benefit workers in agrifood systems (FAO 2022). In addition to being impacted by climate events, African workers in agrifood systems are affected by multiple disruptions along the food supply chain, including economic fragility, conflict, and global shocks such as COVID-19 and the Russia–Ukraine conflict, which limit access to agrifood system production inputs and cause postharvest losses. Agrifood system workers and their households are in clear need of social protection, which has been proven to positively impact food security, nutrition, and human development. Moreover, social protection can play a crucial role in reducing the vulnerability of the poorest and most marginalized communities, which often rely on negative coping mechanisms to generate and protect their assets and enhance their economic and productive capacity (Hoddinott et al. 2012). Adapting social protection schemes for agricultural workers in terms of availability, affordability, accessibility and quality is necessary to respond to many of these risks and disruptions, (Sato and Mohamed 2022). Social protection programs can be made relevant to agrifood systems workers in several ways, including providing income-generating activities, linking school feeding programs to local production, and strengthening shock-responsive elements that build resilience against climate and environmental changes. Social protection is thus a powerful risk management tool to reduce the economic vulnerability of households. In Malawi, the provision of improved seeds and fertilizer to farmers in 1998 through the universal Starter Pack program, under which every smallholder farmer received enough seeds and fertilizer to plant 0.1 hectares of land, contributed to an estimated 67 percent increase in maize output, with maize production reaching 2.5 million tons (Levy 2005). Similarly, sorghum production has increased among recipients of the Lesotho Child Grants Programme (CGP), in which members of poor and vulnerable households receive an unconditional cash transfer quarterly, with the requirement that the money be spent on children (Pellerano et al. 2014). The program helps smooth consumption patterns and builds basic capacity by improving access to a variety of social services, such as education, housing, income transfers, and food provision (Van Ginneken 2005). At the same time, the regularity and predictability of social protection instruments help households improve their resilience to shocks and engage in more profitable livelihood and agricultural activities. The lack of access to funds to invest in livestock and agricultural inputs remains a major barrier to production, but evidence from conditional and unconditional cash transfer programs demonstrates that social protection programs can also increase livestock ownership and use of agricultural inputs. For example, in Ethiopia, the Productive Safety Net Program has led to an increase in livestock holdings in participating households (Andersson et al. 2011). Similarly, the Zambia Child Grant led to a 36 percent increase in worked land as well as an increase in the use of agricultural inputs such as seeds, fertilizers, and hired labor (FAO 2014b). In addition, the Lesotho CGP has resulted in an increase in the use of agricultural inputs such as pesticides (FAO 2014a).

Amid changing market and climate conditions, smallholders must constantly adapt their farming and livelihood systems to ensure resilience and sustainability. Similarly, small and medium enterprises (SMEs) processing raw materials supplied by smallholders need to adapt to changing market, technological, and political conditions. Such adaptations require multiple resources, including short-term finance for working capital, medium- to long-term finance for natural capital and infrastructure improvements, and technology with associated investments. However, financial markets are often not adapted to the realities and needs of smallholders and agricultural and forest SMEs (Louman et al. 2020). While microfinance has become increasingly available for smallholders over the past two decades, it is usually short term, limited to nominal amounts, and may be intended to cover operational or subsistence costs. Attracting investments in any business of a larger scale, on the other hand, usually requires a credit record, collateral, and the promise of secure returns, making such investments less accessible for smallholders and SMEs in agricultural and forest sectors. Viable strategies are needed to reduce perceived or real financial risks for smallholders and SMEs in the agriculture, forestry, and other land use (AFOLU) sectors. Recent years have seen a surge of innovative risk reduction strategies accompanying innovative finance schemes such as government guarantees, first loss loans, or shared risks that mix public and private money (known as "blended finance"). While these elements make it more acceptable to invest in higher-risk ventures and thus may increase access to finance for smallholders and SMEs in AFOLU sectors, they tend to address the risks of investors rather than those of smallholders, SMEs, and the local lending institutions or programs interacting with them. However, innovative approaches aim to facilitate access to finance to Africa's smallholders and SMEs in AFOLU sectors. For instance, Nigeria's Incentive-based Risk Sharing System for Agricultural Lending (NIRSAL), a US$500 million fund generated entirely by public resources, was launched in 2013 through a joint initiative of the Central Bank of Nigeria, the Nigerian Bankers' Committee, and the Federal Ministry of Agricultural & Rural Development. NIRSAL's corporate mandate is to "forge partnerships between agriculture and finance; maximizing the potential of agriculture for food security, job creation, and economic growth" (FAO-IFAD-AGRA 2021). NIRSAL focuses on high-potential value chains by de-risking agricultural value chains and agricultural finance and building long-term capacity of value chain actors and other stakeholders. In addition, it institutionalizes incentives for agricultural finance and value chain performance. Through its partial credit guarantee facility of US$300 million, NISRAL provides loan-level, first-loss coverage on banks' losses ranging from 30 percent to 75 percent of a loan's face value depending on the value chain segment. Credit facilities extended to all segments of agricultural value chains are eligible for individual, loan-level risk sharing coverage. In addition, its insurance facility of US$30 million aims to expand agricultural insurance products and outreach to retail and meso-level players, with a specific focus on moving away from traditional indemnity-based products to parametric, index-based solutions that provide risk transfer products to protect producers against yield and price risk. NISRAL also has a technical assistance facility (TAF) of US$60 million intended to provide supply- and demand-side technical assistance to address various knowledge, operational, and technical gaps so that financial institutions can lend sustainably to the agricultural sector. TAF also supports farmers to adopt good agricultural practices, technological advancements and know-how, and business upgrades to make them more bankable. Furthermore, NISRAL's bank rating scheme of US$10 million rates participating financial services providers and state governments on the effectiveness and outreach of their agricultural lending and social and environmental performance, providing cash and noncash rewards to further incentivize performance. Finally, it has a bank incentives scheme of US$100 million to provide cash, which, along with its bank rating scheme, incentivizes continued outreach and builds long-term capabilities to lend to agriculture (FAO-IFAD-AGRA 2021).

Conclusion

The climate is changing in Africa, as in the rest of the world, and its impacts are real. Africa is experiencing a change in precipitation patterns, a rise in sea level, and an increase in the frequency and intensity of extreme weather events such as droughts, floods, heat, and cyclones. These extreme weather events are negatively impacting economies and displacing communities. Understanding the impact of climate change on economies and opportunities for agrifood system transformation is crucial for sound policies in the context of the post-Malabo Agenda. This chapter aims to achieve that objective by first reviewing the macroeconomic effects of climate change through an analysis of relevant impact pathways and available empirical evidence. In addition, the chapter highlights issues related to agrifood systems and climate change by analyzing the characteristics of agrifood systems and discussing the impacts of climate change on food system activities and actors. The study also identifies both opportunities and barriers to transforming African food systems under climate change.

The chapter shows that the detrimental impact of climate change on economies is generally confirmed by likely reductions in GDP, especially in the agricultural sector. Economies could be impacted through several channels including productivity change, employment, price change, and trade. Further analysis of agrifood systems as important economic components identified three types of agrifood systems: traditional, modern, and transitional (that is, moving from the traditional to the modern category). The ability of agrifood systems to prevent, anticipate, absorb, adapt, and transform rapidly in the face of shocks and stresses depends on their stage of development. The heavy dependence on climatic, biological, physical, and chemical processes makes agrifood systems potentially vulnerable to multiple climate shocks, including extreme weather events, pest and disease outbreaks, water scarcity, and deteriorating natural resources. Existing structural deficiencies, such as inadequate roads, power, irrigation, clean water, processing, storage, and marketing infrastructure, also exacerbate climate shocks on agrifood systems. These shocks will likely affect, to varying degrees, all components of the agrifood system, including production, processing, trade, and consumption. Climate change also has diverse effects on actors within and between different components of agrifood systems. This chapter highlights certain opportunities and barriers to transforming the African agrifood system under climate change, including modern African technologies for climate change adaptation and mitigation, an increase in trade, digital solutions for climate information, the establishment of social protection programs to benefit agrifood system workers, and access to finance. Policies aiming to deal with the impacts of climate change must consider macroeconomic effects, with an emphasis on agrifood systems. Investing or repurposing support to relevant interventions is also crucial for economic resilience, allowing agrifood systems to better adapt to climate change.

CHAPTER 4

Exploring Methane Emissions in Africa

Jean Paul Latyr Faye, Mansour Dia, Khadim Dia, and Racine Ly

Introduction

In the 21st century, climate change has emerged as one of the most pressing human and environmental crises. The primary driver of this global challenge is the accumulation of greenhouse gases (GHGs), such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), in the atmosphere. In analyzing Africa's contribution to the global GHG budget,1 it is essential to consider two factors: the absolute emissions of the continent and their role in the global carbon cycle. It is well known that Africa's GHG emissions are relatively low on a per capita basis, but they are rising due to population growth, urbanization, and increased human activities. According to new studies (Mostefaoui et al. 2024), Africa's methane emissions are steadily increasing. This trend reflects both agricultural development and environmental factors, such as increased forest fires due to aridity and climate variability, including the effects of El Niño.

Climate change is a global phenomenon, but its impacts vary across continents, with Africa being particularly vulnerable (Kogo, Kumar, and Koech 2021; Malhi, Kaur, and Kaushik 2021). The greater impact on African countries can be attributed to numerous factors, such as the changes in weather patterns, including more frequent and intense heatwaves (Parkes, Buzan, and Huber 2022) and the increase in droughts (Cook, Mankin, and Anchukaitis 2018), floods (Winsemius et al. 2018), and storms (Allen 2018).

Most discussions of climate change mitigation and adaptation in Africa have focused on CO_2. This focus is understandable, given that the concentrations of CH_4 (~1,750 parts per billion [ppb]) and N_2O (~310 parts per billion [ppb]) are significantly lower than those of CO_2 (~386 parts per million [ppm]) (Reay, Smith, and van Amstel 2010). However, reducing methane emissions has recently attracted substantial attention as a potentially more effective strategy to mitigate global warming, due to methane's capacity to absorb and re-emit infrared radiation (heat) and its relatively short lifetime in the atmosphere, of around 12 years (Skytt, Nielsen, and Jonsson 2020). Indeed, the removal of 1 metric ton2 of CH4 corresponds to the removal of around 84 to 86 tons of CO2 over 20 years and 28 to 34 tons over 100 years (Lee et al. 2023).

In addition, in climate change projections, the impact of rising temperatures and rainfall on CH_4 emissions is greatly underestimated. For example, in examining the global methane budget (Reay, Smith, and van Amstel 2010), it appears that a wide range of natural and anthropogenic sources are balanced with very few, often radiative reinforcing sinks. The sources are estimated to emit between 500 and 600 teragrams (Tg; 1 teragram = 1 million tons) of CH_4 per year on average, while the sinks are estimated to remove between 460 and 580 Tg of CH_4 per year. Based on the above figures, the global community must deal with a balance of between +20 and +52 Tg of CH_4 per year (Reay, Smith, and van Amstel 2010). However, this analysis does not consider the impacts of rising temperatures and rainfall on the emissions of methane. Indeed, methane is also known to have climate-positive feedback, which means its presence in the atmosphere will also lead to more methane emissions. For instance, the methane emissions growth rate was almost null from the late 1990s to the beginning of the 21st century, and then it increased in 2007 and 2008 due to a temperature increase that melted permafrost. Heavy rainfall during the same period also enhanced methanogenesis in many areas (Dlugokencky et al. 2009). Another example of positive feedback for methane can be found in wetlands. Research has shown that wetland methane emissions depend mainly on temperature, water table depth, and substrate availability. While the degree of sensitivity of wetlands' methane emissions to those parameters is poorly understood, temperature is often the dominant factor of the three. The logic of methane's positive feedback is that methane contributes to global warming (increased temperature), and the increased temperature contributes to even more methane emissions.

In Africa, despite the political will to combat climate change, various barriers can impede the effective design and implementation of policies and interventions to combat climate change and climate variability. One of the most prominent barriers is the lack of data on the dynamics of GHG emissions to inform those policies and interventions. Indeed, accurate measurement and tracking of greenhouse gas emissions are critical for developing effective climate policies and mitigation strategies. While the Intergovernmental Panel on Climate Change has provided comprehensive good practice guidance (Yaman 2024) to aid researchers

1 "Budget" refers to the absolute difference between emissions and removals of a particular GHG.

2 All tons are metric tons throughout.

and governments in estimating and reporting GHG emissions, there remains a significant gap in primary data collection, particularly in African countries. This gap is especially pronounced when applying Tier 1 methods,[3] which are often based on conservative assumptions and generalized data and can lead to potential under- or overestimations of actual emissions. Such a lack of data makes climate reporting subject to inaccuracies, leading to under- or overestimation in the GHG budget, particularly with regard to methane, in African countries.

In this chapter, we use satellite remote sensing data to address the gaps in methane emissions data across African countries, in light of the growing recognition that reducing methane emissions might be a more effective strategy for mitigating global warming. The main objectives of this chapter are threefold: (1) to assess current methane concentrations across the entire continent using satellite remote sensing data, (2) to explore the relationship between methane emissions and crop types cultivated, and (3) to analyze the potential relationship between methane concentration trends across cropland and climate parameters such as temperature and rainfall. With this comprehensive data analysis, we aim to identify trends, patterns, and spatial distributions of methane emissions and examine their concentrations over time and across different geographical locations and crop types to uncover critical insights into the drivers of methane emissions. To accurately assess methane emissions from cropland, we selected reference sites with no human activities, in order to evaluate natural methane emissions. This technique helps us determine the amount of methane emitted from cropland due to anthropogenic activities.

Methodology

It is essential to clarify the sources of methane emissions to gain a deeper understanding of methane concentration measurements over croplands. This section explores the known sources and fundamental mechanisms of methane emissions. It also describes the measurement techniques, specifically remote sensing, used to assess methane concentrations across African croplands.

Sources of Methane Emissions in Africa

Methane emissions can originate from natural and anthropogenic sources. The primary natural sources of methane emissions are wetlands, termites, and onshore and offshore geological releases.

Among natural sources, wetlands are the most significant contributors to methane emissions, accounting for more than a quarter of global CH_4 emissions (Määttä and Malhotra 2024). The wetlands environment encompasses various waterlogged ecosystems such as marshes, swamps, and peatlands, which serve as fertile grounds for methanogenesis, a microbial process that occurs in oxygen-deprived conditions. Wetlands emit methane through the anaerobic decomposition of organic matter, including plant material and soil organic carbon. The three main factors influencing methane emissions from wetlands are temperature, water table depth, and substrate availability. Though the extent to which methane emissions are affected by changes in these factors is still poorly understood, the dynamics of methane emissions from African wetlands are closely intertwined with climate change (Abdelkrim, Laila, and Ahmed 2022; Bandh et al. 2021). Indeed, warmer temperatures can accelerate microbial activity and boost methanogenesis rates, increasing wetland methane emissions (Chen et al. 2020; Cui et al. 2015). Similarly, alterations in precipitation patterns and hydrological regimes can affect the extent and duration of wetlands' waterlogged conditions, thereby influencing methane production and emission dynamics (Chatterjee et al. 2024). For instance, prolonged drought followed by intense rainfall can create ideal conditions for methane release by promoting the decomposition of organic matter in waterlogged soils. Furthermore, the cyclic relationship between wetland methane emissions and climate change exacerbates the situation.

While generally less significant than wetland contributions, methane emissions from geological sources still play a role in the overall methane cycle. These emissions primarily originate from natural phenomena such as seeps, mud volcanoes, and geothermal or volcanic areas. Additionally, other natural sources such as termites, oceans, methane hydrates, wild animals, and fires contribute to methane emissions, but their impact is relatively minor compared to that of wetlands.

3 Tier 1 refers to the first-level methodology provided by the Intergovernmental Panel on Climate Change and the application of default emission factors for GHG inventories.

Anthropogenic activities play a significant role in methane emissions across Africa. Agricultural activities, particularly rice cultivation and livestock farming, are substantial contributors to methane emissions on the continent (Van Amstel 2012). In modern agriculture, one of the most employed techniques in rice cultivation involves the application of organic amendments. These amendments enhance soil fertility, increase crop yields, and facilitate soil carbon sequestration.[4] This mechanism stands out as one of the most significant agricultural sources of methane, contributing approximately 8 percent of global anthropogenic emissions (Ouyang et al. 2023). In rice paddies, flooded fields create anaerobic conditions conducive to methanogenesis, resulting in substantial methane emissions during microbial decomposition of organic matter in soil and water.

Another agricultural source of methane emissions is enteric fermentation in ruminant livestock, such as cattle, sheep, and goats, which produces methane as a by-product of microbial digestion in their rumen (Joseph 2024). Livestock emissions account for a significant share of methane emissions from the agricultural sector in Africa.

Early natural and agricultural fires in conditions where biomass retains some moisture, as is often the case in Africa's fire-prone savannas, also lead to CH_4 release.

The energy sector is another important source of anthropogenic methane emissions in Africa (Usiabulu et al. 2024). Oil and gas extraction, processing, and distribution activities, as well as coal mining, contribute to methane emissions through fugitive emissions, leaks, and venting of natural gas. The incomplete combustion of biomass and fossil fuels in household cooking and heating also releases methane and other GHGs into the atmosphere. Waste management practices, including landfill disposal and organic waste decomposition, produce methane as a by-product of anaerobic decomposition processes (Cusworth et al. 2024).

In summary, methane emissions in Africa arise from natural processes, such as wetland emissions correlated with climate change and climate variability, as well as anthropogenic ones, including agriculture, energy production, and waste management.

Measurement Techniques and Quantification of Methane Emissions

This subsection details the measurement techniques employed for quantifying methane emissions and discusses the concentration parameter used to assess the amount of methane released into the atmosphere.

Techniques for Measurement of Methane Emissions

Two primary methods exist for measuring the methane emitted into the atmosphere. One approach is the bottom-up method (Desjardins et al. 2018), while the second approach, the top-down method (Desjardins et al. 2018), typically involves measuring atmospheric methane concentrations using airborne or satellite sensors to infer emission releases. The latter approach, the method used in this study, requires further discussion, especially with regard to its use in Africa. However, it is essential to first delineate the bottom-up approach more explicitly.

The bottom-up measurement approach can be used to assess methane emissions. It offers insights into methane production and release dynamics. It involves using ground-based measurement stations strategically positioned around the world, with the measurement outputs applicable for use in Africa. These stations employ sophisticated instrumentation to measure atmospheric methane concentrations directly, providing accurate and detailed data on local emissions sources and trends. Mobile measurement campaigns, where instruments are mounted on vehicles or aircraft, can offer spatially comprehensive coverage, allowing researchers to capture emissions variability across diverse landscapes and land use types (Shaw et al. 2022).

The top-down method for assessing methane emissions involves applying remote sensing techniques such as those deployed via satellites. Remote sensing techniques allow for the measurement of methane gas emissions from various locations on Earth, including cropland and non-cropland areas, without requiring direct physical contact. Measuring the emitted methane without direct contact offers numerous advantages, especially when the reference area is in a location with limited human access. Advancements in satellite technology have

4 For example, the use of nitrogen fertilizers can reduce microbial activities that consume methane in soil. This results in less methane being oxidized and removed from the atmosphere.

significantly enhanced our understanding of the extent and characteristics of methane emissions. Remote sensing techniques provide accurate and comprehensive data on a global and regional scale, allowing for continuous monitoring and precise measurement of methane emissions (Liu et al. 2021). The high resolution of today's satellite imagery and the advanced sensors enable the detection of methane leaks and sources with greater accuracy (Zhang, Comas, and Brodyle 2020).

In this study, we obtained our results using the TROPOspheric Monitoring Instrument (TROPOMI) on board the Sentinel-5 Precursor (S5P) satellite (Guanter et al. 2015; Vries et al. 2016), a mission initiated by the European Space Agency. TROPOMI samples the 675–775 nm spectral window with a high spectral resolution and a pixel size of 49 km^2. TROPOMI detects sunlight reflected or scattered by the Earth's surface and atmosphere. In this way, TROPOMI provides high-resolution measurements of methane concentrations in the atmosphere, enabling the monitoring of large-scale emission patterns across both cropland and non-cropland areas in African countries. Tracking methane emission concentrations via TROPOMI data necessitates processing and analyzing the retrieved spectra (Vries et al. 2016). The technique involves processing data from TROPOMI to quantify the concentration of methane emissions. This quantification provides insights into spatial and temporal variations of methane levels, enabling the identification of hot spots, trends, and potential emission sources, such as those from the agricultural sector. Moreover, TROPOMI data can be integrated with other environmental datasets, such as land cover maps and meteorological data, to better understand the factors influencing African methane emissions.

While TROPOMI presents several advantages for assessing the methane emission concentration, it also entails certain limitations. Cloud cover, aerosol interference, and surface reflectance variations may affect the accuracy and reliability of methane measurements obtained from TROPOMI data (Kooreman et al. 2020). Despite these challenges, TROPOMI remains a valid option for Africa to monitor methane emissions extensively. In the following subsection, we describe how the emitted methane can be quantified in specific regions of the atmosphere.

Quantification of Methane Emissions

TROPOMI data offer the flexibility to employ various parameters for quantifying the amount of methane emitted into the atmosphere (Jacob et al. 2016; Reinelt et al. 2017). We focus on the concentration parameters to quantify the methane produced by cropland and animals during farming activities. The concentration parameters hold particular significance because (1) they are able to provide a direct measure of the density of methane molecules in the atmosphere at a given time and location, and (2) the quantification of methane emissions allows for the measurement of additional characteristics of methane emissions, including emission flux, emission rate, and isotopic composition. Moreover, methane concentration data from TROPOMI are easily accessible regardless of a country's conditions on the ground. The concentration is often expressed in units such as parts per million by volume (ppmv) or parts per billion by volume (ppbv), the number of molecules of a specific GHG per billion molecules of air. It offers a snapshot of atmospheric methane levels, allowing for comparisons across regions and periods. Thus, the concentration measurements serve as a fundamental basis for understanding the spatial distribution, temporal variations, and overall trends in methane emissions.

Results

This section presents the research results, including data collection and the average methane emissions concentration above croplands, both at the continental and country level, for 2023. Additionally, it explores the trend relationships between methane emissions and climatic parameters such as temperature and rainfall.

Dataset Collection and Interpretation

In this study, we used methane data collected from TROPOMI. This state-of-the-art instrument serves as the primary payload of the S5P mission operated by the European Space Agency. TROPOMI is a nadir-viewing shortwave spectrometer, meaning it captures data by looking directly downward from its orbit, covering a wide area of the Earth's surface. TROPOMI employs a passive remote sensing technique, which measures radiation reflected by or emitted from the Earth's surface and atmosphere.

The instrument operates at the top of the atmosphere, collecting data in multiple wavelength ranges, including the ultraviolet-visible, near-infrared, and shortwave infrared spectra. This broad spectral coverage allows TROPOMI to detect various atmospheric gases, including methane, with high sensitivity. TROPOMI has a sophisticated two-detector sensor that captures detailed information across these spectral ranges. Each measurement made by TROPOMI is taken within a swath, a strip of the Earth's surface that the instrument observes during a single pass. TROPOMI has a 7 km swath, allowing it to cover large areas in just a few seconds. The instrument continuously collects data as the satellite moves along its flight path, creating a comprehensive global dataset.

The data collected for each swath are organized into two key components. The first component provides the spatial positioning information, indicating the exact location within the swath where the measurement was taken. These geolocation data are crucial for mapping the distribution of methane concentrations across different regions. The second component contains the spectral information, which includes the specific wavelengths of light measured by the instrument. These spectral data are essential for identifying and quantifying methane concentrations in the atmosphere, as different gases absorb light at distinct wavelengths. Combining these two components, TROPOMI delivers highly detailed and accurate methane concentration measurements. The data are clipped to the region of interest (continental and country levels).

We also used the Global Land Cover dataset from Copernicus. Classes of land use / land cover (cropland, bare/sparse vegetation) are isolated into single TIFF files. We masked the methane data with the resulting TIFF files to obtain the methane emissions from a specific land use class. Then, to obtain the results of this work, we applied several spatial and temporal aggregations of the processed methane data. We used a seven-step rolling average for visualization to smooth the plots and remove internal fluctuations.

The study also uses rainfall and land surface temperature data collected by the Climate Hazards Center at the University of California and the Moderate-Resolution Imaging Spectroradiometer (MODIS), respectively. The data sources used in this chapter are summarized in Table 4.1.

TROPOMI provides direct measurements of methane concentrations in the atmosphere, with a particular sensitivity to the lower layers of the atmosphere. Unlike other methodologies of methane concentration measurement, TROPOMI data do not specifically account for industrial processes. Instead, they are more responsive to natural processes that emit methane, such as enteric fermentation from livestock, agricultural practices, wetlands, and other biogenic sources.

TABLE 4.1 — DATA SOURCES USED IN THIS STUDY

Indicator	Product name	Source	Spatial resolution
Methane	TROPOMI Total Column CH4	Copernicus	7 km x 7 km
Land use / land cover	Global Land Cover products	Copernicus Global Land Service	100 m
Rainfall	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	Climate Hazards Center, UC Santa Barbara	0.05 degree
Land surface temperature	Land Surface Temperature/ Emissivity 8-Day (MOD11A2) Version 6.1	Moderate Resolution Imaging Spectroradiometer (MODIS)	1 km x 1 km

Source: Authors.

Because TROPOMI is designed to capture atmospheric methane concentrations and not those associated with industrial activities, it will therefore likely detect emissions from natural processes.

As a result, the lower methane concentrations observed in some African countries via TROPOMI data do not necessarily indicate that these countries emit less methane overall. Instead, it reflects the types of methane-emitting processes detected by TROPOMI. Therefore, the results presented in this chapter should be interpreted with the following considerations:

- **High methane concentrations** detected by TROPOMI in each country suggest that natural processes contributing to methane emissions are prevalent and measurable through remote sensing techniques.
- **Low methane concentrations** in a country imply that either the natural processes emitting methane are less significant, or they are not as easily captured by TROPOMI's remote sensing capabilities. Thus, TROPOMI data should be understood as a reflection of methane emissions primarily

from natural processes rather than a comprehensive measure of all sources, including industrial processes.[5]

Average Methane Emissions at the Continental Level

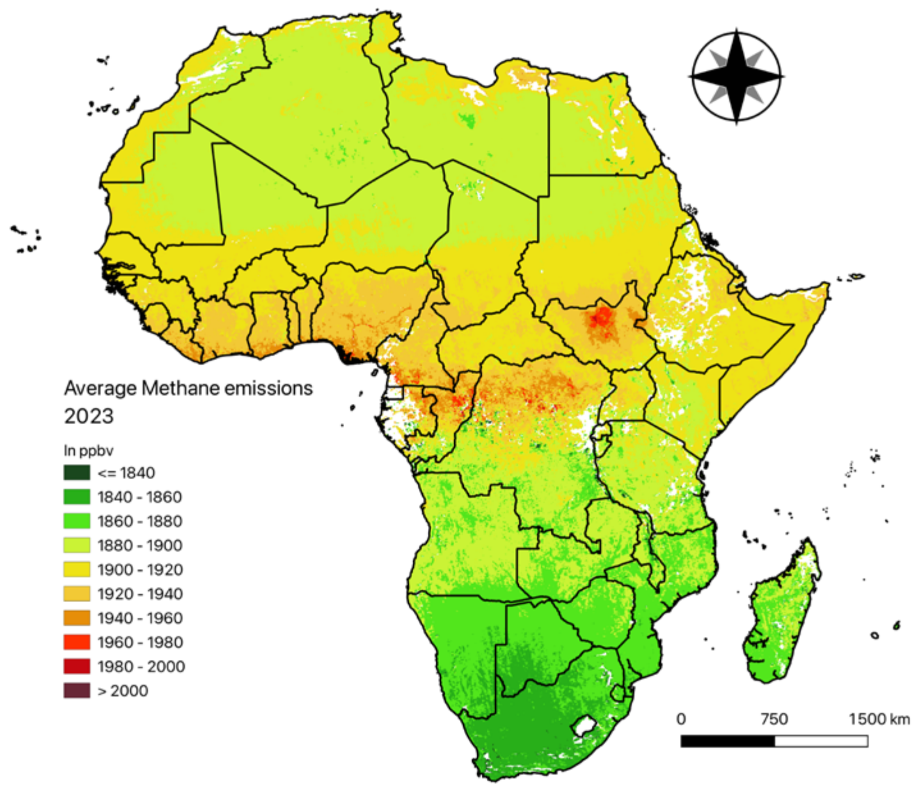
The continental average methane emission calculation is confined solely to African cropland areas to assess methane emissions specifically from agricultural activities.

Figure 4.1 presents the average methane emissions across the continent, with concentrations expressed in ppbv, representing the number of CH4 molecules per one billion molecules of ambient air. The spatial distribution of methane emissions from natural processes reveals distinct patterns, trends, and regional variations across Africa. The results show that southern Africa experiences relatively fewer natural processes that emit methane, with concentration levels ranging from 1,840 to 1,880 ppbv. In contrast, the countries in the Sahel region exhibit higher levels of methane emissions, driven by more significant natural processes, with concentrations reaching up to 1,980 ppbv. In northern Africa, methane emissions are moderate, with concentration levels between 1,880 and 1,920 ppbv, reflecting the limited presence of methane-emitting natural processes in the region.

Additionally, the continental analysis highlights some regions with high methane concentration levels. For instance, South Sudan shows methane concentrations reaching up to 2,000 ppbv, marking it as a region with exceptionally high emissions from natural processes. More investigation would be needed to better understand the reason for such a peak.

While our research for this chapter has not collected data to elucidate such a fact, the lower emissions level in the southern region could be partly attributed to a less intensive livestock presence and activities. In addition, there is a presumption of more "untouched" landscapes in the southern regions, where human influence is less, leading to a better equilibrium in GHG budgets. Other hypotheses that could explain the differences in methane emissions include the scale of farming operations, the use of advanced technology and machinery, investment in irrigation and fertilization, and the influence of governmental policies supporting agricultural development. Additionally, variations in land use practices, such as different approaches to crop rotation, soil conservation techniques, and land tenure systems, also play a significant role. The differences in geographical conditions, climate patterns, and economic priorities could also help explain the variations.[6]

FIGURE 4.1—AVERAGE METHANE EMISSIONS IN AFRICA, 2023



Source: Authors.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

5 Industrial processes should be understood as the associated processes and emissions of by-products in the course of production. Satellites can only measure the emissions of by-products, not emissions related to processes.

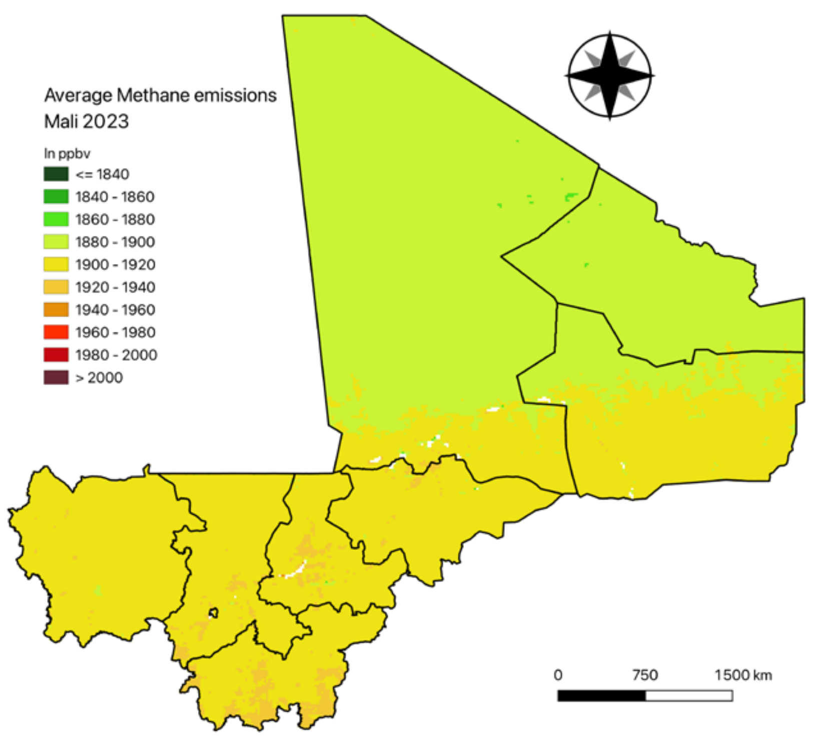
6 All these potential explanations show the need for more ground data to better elucidate the emissions sources and their geographical and temporal dynamics.

Average Methane Emissions at the Country Level

In the preceding subsection, we analyzed methane emissions at the continental level. This subsection focuses on four use case countries—Mali, Niger, Nigeria, and Namibia—to provide a more detailed examination at the national level. Conducting country-level analyses of methane emissions can provide more insights into the spatial distribution and magnitude of each country's emissions, highlighting areas of concern and opportunities for targeted mitigation efforts. Like the continental average analysis, data from TROPOMI for 2023 are used to investigate country-level methane emissions. It is worth noting that the investigation into methane emissions in these four countries was conducted alongside analyses of other countries; however, we cannot present all the results for every country in this chapter. It is also important to mention that the four countries were not chosen based on any rigorous selection criteria; instead, we simply aimed to show some use cases to analyze methane emissions across the continent. As the data necessary to explain the intensity of methane emissions across each country were not available when we were writing this chapter, we limit ourselves to presenting the observed results rather than providing rigorous explanations. However, we propose some hypotheses that could account for the variation in methane intensity in certain areas. These hypotheses will require further investigation in subsequent research.

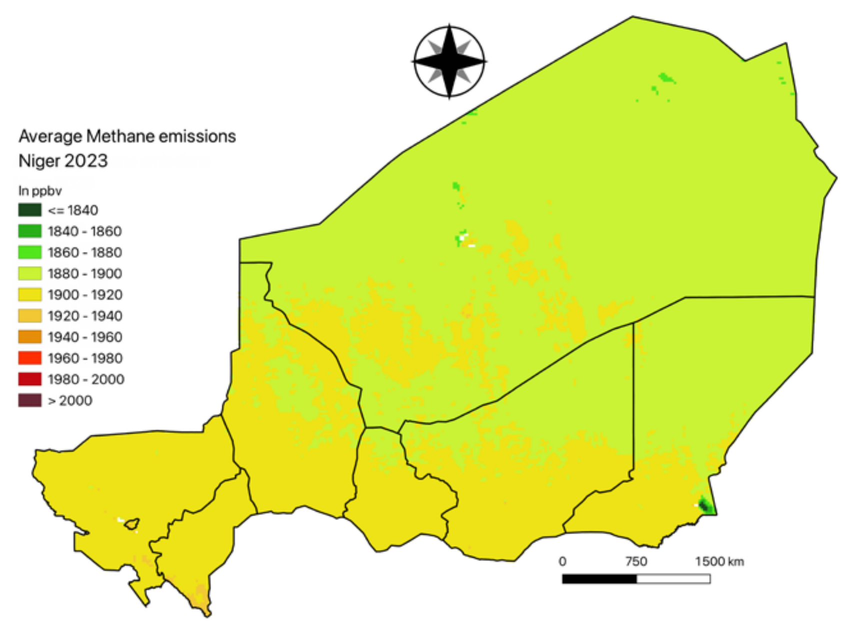
Figure 4.2 displays the average methane emissions for Mali in 2023. The results indicate that the southern region has the highest concentration of methane emitted by natural processes, reaching up to 1,960 ppbv, whereas the northern region has a moderate concentration of 1,840 ppbv. Mali's methane

FIGURE 4.2—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN MALI, 2023



Source: Authors.

FIGURE 4.3—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NIGER, 2023



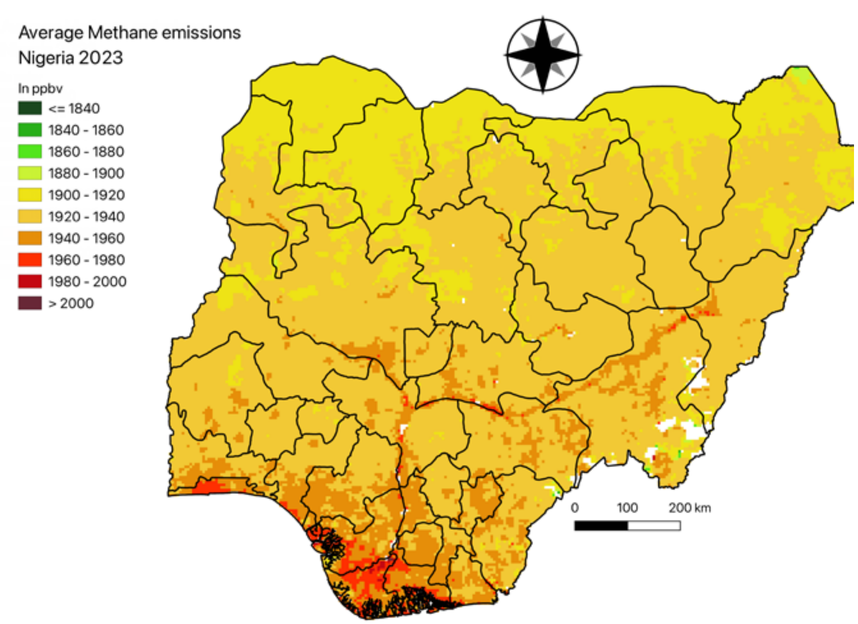
Source: Authors.

concentration level is likely produced primarily through enteric fermentation from livestock and anaerobic decomposition in irrigated rice farming.

Figure 4.3 illustrates the spatial distribution of methane concentrations for Niger. The southern region has the highest methane concentrations, ranging from 1,920 to 1,940 ppbv, while the northern region has the lowest concentrations, ranging from 1,880 to 1,900 ppbv. These concentrations of methane could be attributed to various processes such as agricultural practices, waste management, and natural sources, necessitating further investigation. The 2021 United Nations Environmental Programme report (UNEP 2021) underscores the urgent need for improvements in agricultural practices and urban waste management to address these emissions of methane effectively.

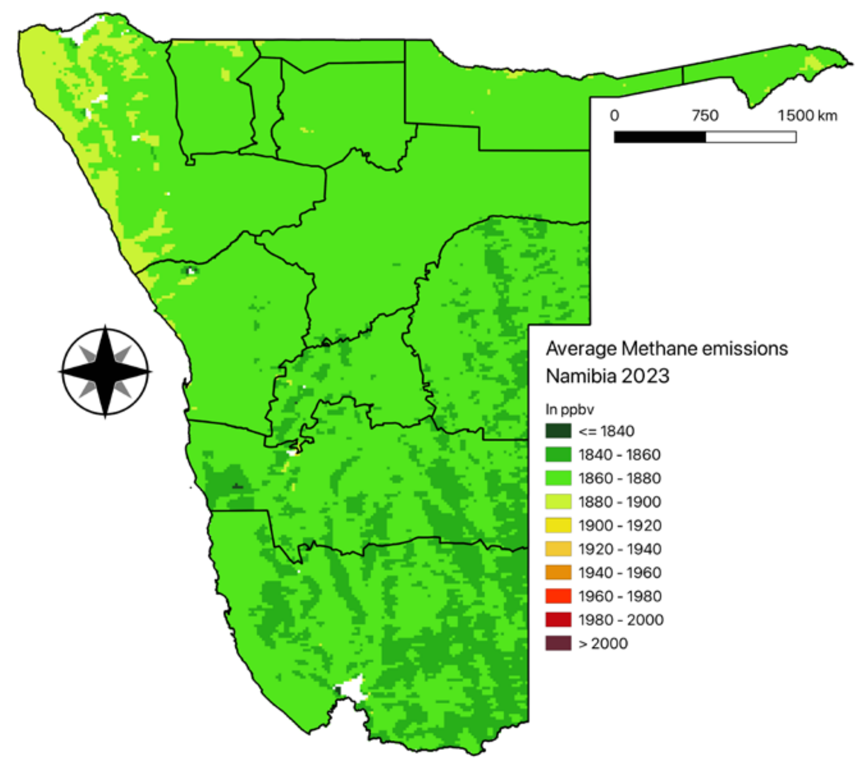
Figure 4.4 shows the average methane concentrations in Nigeria. The southern region exhibits the highest concentrations, ranging from 1,980 to 2,000 ppbv, whereas the northern region has the lowest concentrations, from 1,900 to 1,940 ppbv. Even if southern Nigeria is known for its higher forest density and mangroves, the sinks of methane gases may not be sufficient to reduce the amount of CH4 released. Nigeria exhibits the highest average methane emissions of the four use-case countries. The geographical disparity in Nigeria suggests that regional variations in climate, land use, and socioeconomic factors may influence methane production and release. Intensive agricultural practices, urbanization, and industrial activities in the southern regions contribute to higher methane emissions (Nwaneke and Chude 2015). Indeed, Nigeria's methane emissions are closely tied to its status as Africa's largest oil producer. The oil and gas sectors and the wetlands, particularly in the Niger Delta, are significant contributors, with practices such as gas flaring and oil leaks prevalent (IEA 2023).

FIGURE 4.4—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NIGERIA, 2023



Source: Authors.

FIGURE 4.5—SPATIAL DISTRIBUTION OF AVERAGE METHANE EMISSIONS IN NAMIBIA, 2023



Source: Authors.

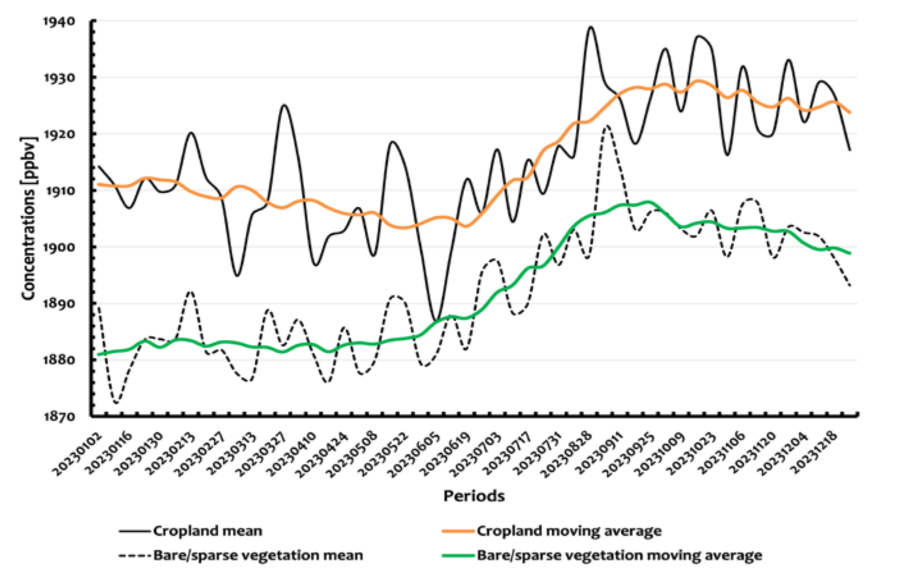
Figure 4.5 depicts the methane concentration in Namibia. With the lowest methane emissions, Namibia's situation reflects its lower natural processes. As previously discussed, the lower methane concentrations observed by TROPOMI are primarily due to natural processes and do not account for methane produced as a by-product of industrial activities. In other words, the methane concentrations shown here reflect only the emissions from natural processes, which does not imply that Namibia emits a lower total amount of methane than other African countries. In fact, according to the African Development Bank report on methane emissions in Africa, southern Africa remains one of the top methane-emitting regions on the continent.

Agricultural Methane Emissions

In analyzing methane emissions from natural processes in Africa, a crucial aspect is comparing emissions from agricultural (anthropogenic sources) and nonagricultural (natural sources) land. Nonagricultural land areas are sites free from human interference that remain untouched by activities such as construction, farming, or urban development. These sites provide a natural environment, allowing for the observation of ecological processes and environmental conditions without the influence of human activities. The agricultural sector, mainly rice cultivation, is a significant source of methane emissions, anaerobic decomposition, and other processes. By subtracting methane emissions from agricultural land with those from nonagricultural land, we can discern the extent to which human activities amplify methane emissions.

We used moving averages to enhance the interpretation by smoothing out short-term fluctuations, highlighting underlying patterns and possible correlations between cropland and non-cropland methane concentrations within the studied countries. Our results show a clear difference between methane emissions from agricultural and nonagricultural land, with cropland exhibiting higher concentrations. The substantial increase in methane emissions observed during the growing season is particularly striking. However, it is noteworthy that this disparity also persists both before and after the growing season, albeit to a lesser extent. This suggests that while growing-season activities predominantly drive the significant surge in methane emissions, other environmental factors may also exert influence. The differences observed outside the growing season may be attributed to correlations between methane emissions and climatic parameters such as temperature and rainfall.

FIGURE 4.6—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN MALI, 2023



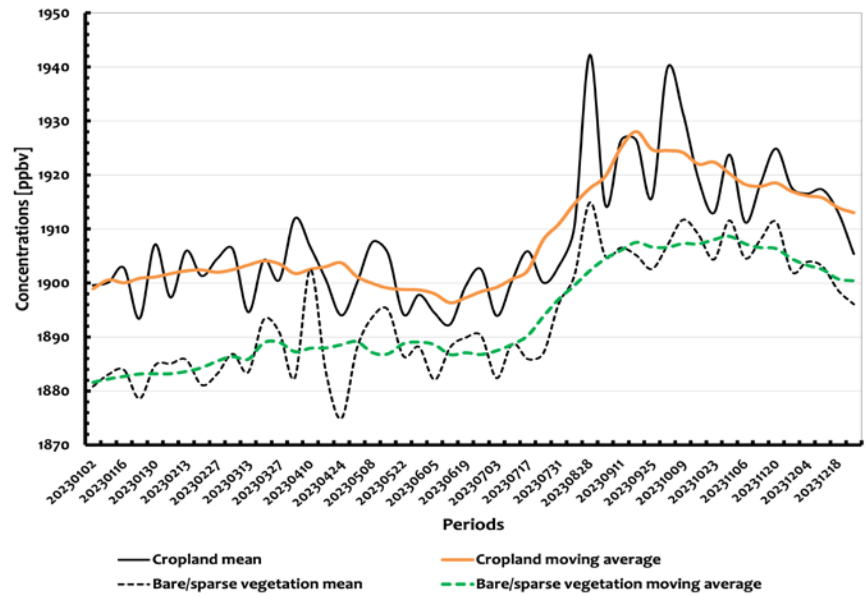
Source: Authors.

In Figure 4.6, we show the concentration of methane over time on cropland and non-cropland in Mali. An increase in methane emissions during the growing season is observed in Mali. The country's agriculture-driven economy relies heavily on livestock rearing and rice cultivation, significantly influencing its methane emission profile. These sectors are particularly methane-intensive due to the prevalence of enteric fermentation in cattle and the anaerobic conditions in irrigated rice paddies, as illustrated by the growing-season data presented in the figure.

Figure 4.7 presents the evolution of methane emissions as a function of time for Niger. As in Mali, a significant amount of methane is released due to agricultural activities. During the rainy season, the increased soil moisture accelerates the natural processes of organic decomposition, leading to a peak in methane emissions. This explains the rise in methane emissions observed during the growing season.

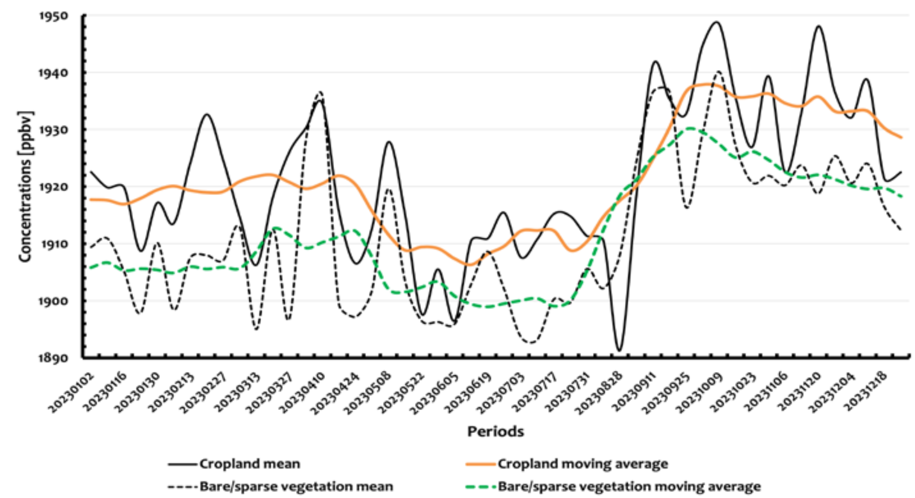
Figure 4.8 illustrates the progression of methane concentration in Nigeria. Extensive livestock holdings and widespread cultivation of methane-intensive

FIGURE 4.7—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGER, 2023



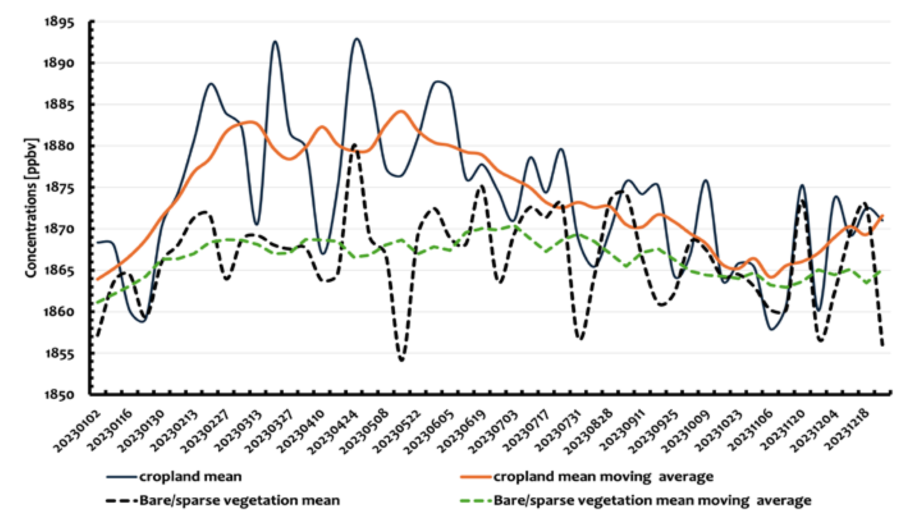
Source: Authors.

FIGURE 4.8—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGERIA, 2023



Source: Authors.

FIGURE 4.9—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NAMIBIA, 2023



Source: Authors.

crops such as rice and yams characterize Nigeria's agricultural landscape. This combination leads to high methane emissions, particularly in the wet seasons, when runoff and waste accumulation peak. These conditions facilitate the anaerobic decomposition of organic material, significantly increasing methane output.

Finally, Figure 4.9 presents the methane emissions in Namibia over time. Here again, there is an increase in methane emissions during the growing season. The anaerobic decomposition of organic material significantly influences this rise.

Correlation Between Climate Parameters and Methane Emissions

This subsection examines the relationship between climate variables—specifically, temperature and rainfall—and methane emissions throughout the year. Our primary focus is understanding how these climate factors influence methane release from cropland, particularly by comparing the differences in methane emissions between cropland and non-cropland areas. This comparison to natural landscapes helps to reveal the extent to which agricultural activities contribute to methane emissions. Additionally, we aim to explore the simultaneous correlation between these climate variables and methane emissions resulting from the methanogenesis process during the agricultural season, including the sowing, growing, and harvesting phases.

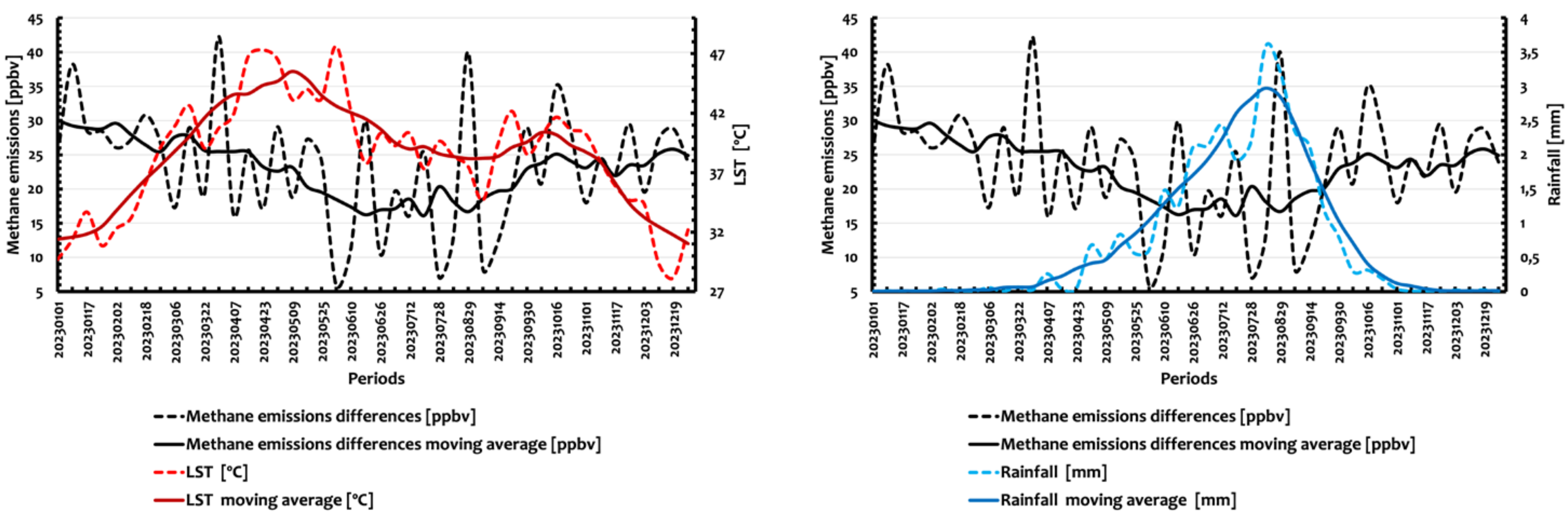
Evolution of Temperature, Rainfall, and Methane Emissions

As discussed in the introduction, it is evident that climate parameters have numerous impacts on agriculture and are likely to affect methane emissions (Omotoso and Omotayo 2023). Therefore, examining the correlation between methane concentrations above croplands with temperature and rainfall anomalies, as a function of time, becomes important. The goal is to investigate the relationship between methane concentration and temperature on one hand and methane emissions and rainfall anomalies on the other to identify trends in methane dynamics. Understanding these trends is essential for clarifying the interactions between methane emissions, climate variables, and emissions from the agricultural sector.

Figures 4.10 and 4.11 show the temporal evolution of temperature and rainfall, alongside the difference in methane emitted between cropland and non-cropland, respectively, in Mali and Nigeria. The figures also incorporate the moving averages with a lag of four months. This multidimensional approach enables an exploration of how variations in temperature and rainfall influence methane emissions from diverse ecosystems and anthropogenic activities.

In Mali (Figure 4.10), the results show a strong correlation between temperature, rainfall, and methane emissions. During the dry season, as temperatures rise, methane emissions decrease. This can be attributed to the lack of water,

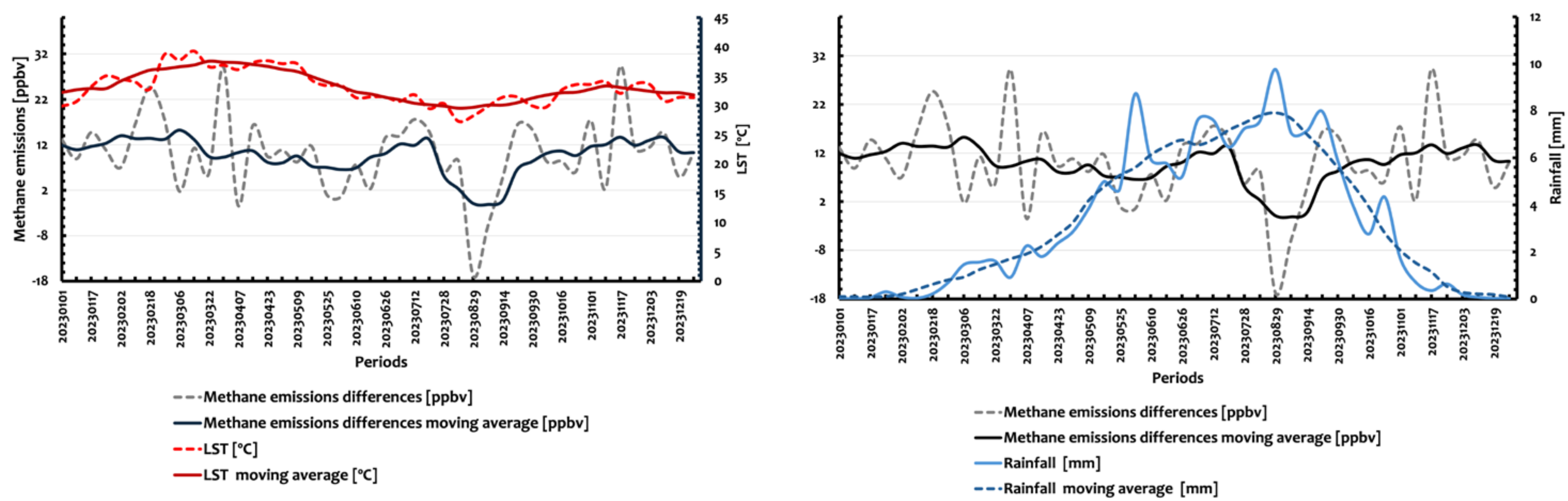
FIGURE 4.10—INFLUENCE OF CLIMATE PARAMETERS ON METHANE EMISSIONS IN MALI



Source: Authors.

Note: Temperature is on the left and rainfall on the right. The black, red, and blue curves represent the methane concentration difference between cropland and non-cropland emissions, temperature, and rainfall, respectively. The solid lines depict the moving averages for each parameter. LST = land surface temperature.

FIGURE 4.11—INFLUENCE OF CLIMATE PARAMETERS ON METHANE EMISSIONS IN NIGERIA



Source: Authors.

Note: Temperature is on the left and rainfall on the right. The black, red, and blue curves represent the methane concentration difference between cropland and non-cropland emissions, temperature, and rainfall, respectively. The solid lines depict the moving averages for each parameter. LST = land surface temperature.

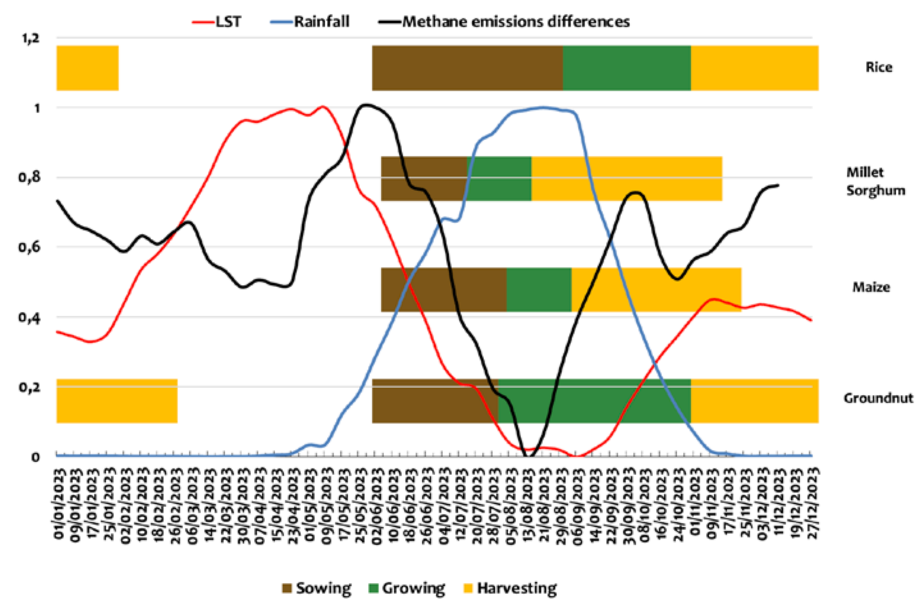
which is essential for the methanogenesis process; as rainfall increases, methane emissions decrease, eventually reaching their lowest point at the peak of rainfall. This decline in methane emissions is associated with the simultaneous decrease in temperature due to the increased rainfall. However, after the maximum rainfall is reached, the conditions become optimal for the methanogenesis process in suitable areas, as there is now sufficient water combined with a gradual temperature rise. This combination of adequate moisture and heat stimulates the methanogenesis process, increasing methane emissions.

In Nigeria (Figure 4.11), during the dry season, rising temperatures decrease methane emissions from natural processes, primarily due to the lack of water, which is essential for methanogenesis. As the rainy season begins, increasing rainfall causes temperatures to drop, resulting in fluctuating methane emissions. These emissions decrease significantly at the peak of rainfall when water availability is at its highest. However, abundant water and gradually increasing temperatures after the peak rainfall create favorable conditions for the methanogenesis process. This process is responsible for the subsequent rise in methane emissions, as the interaction between sufficient moisture and warmth promotes methane production in the environment.

Correlation Between Climate Parameters and Methane Emissions at Sowing, Growing, and Harvesting

To better understand the methane emissions from cropland, we examine methane concentrations at each stage of the agricultural season. The main objective is to elucidate the temporal dynamics of methane emissions in cropland environments. In addition, this study will investigate the possible relationship between crop types and methane emission concentrations. As previously discussed, different crops affect methane emissions to varying degrees.

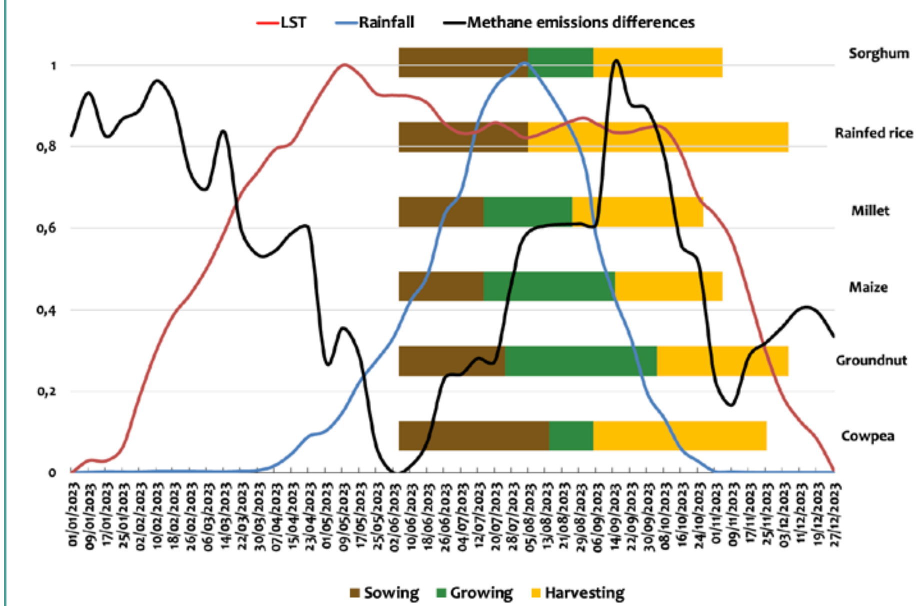
FIGURE 4.12—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN SENEGAL, 2023



Source: Authors.

Note: The agricultural seasons are shown in bar plots, with the sowing season highlighted in brown, the growing season in green, and the harvesting season in yellow, alongside various crop types. The red curve visualizes the temperature and the black curve the methane emissions concentration. The blue curve represents rainfall data for the year 2023. Note that the data have been normalized to the dataset's maximum and minimum values in the global dataset. LST = land surface temperature.

FIGURE 4.13—CONCENTRATION AND MOVING AVERAGE OF METHANE EMISSIONS OVER TIME ON CROPLAND AND NON-CROPLAND IN NIGER, 2023



Source: Authors.

Note: The agricultural seasons are shown in bar plots, with the sowing season highlighted in brown, the growing season in green, and the harvesting season in yellow, alongside various crop types. The red curve visualizes the temperature, and the black curve shows the methane emissions concentration. The blue curve represents rainfall data for the year 2023. Note that the data have been normalized to the dataset's maximum and minimum values in the global dataset. LST = land surface temperature.

In Figures 4.12 and 4.13, the relationship between the agricultural season, temperature, and rainfall is shown for Senegal and Niger, respectively. During the sowing season, rainfall can significantly impact methane emissions. Increased rainfall leads to higher soil moisture levels, which may enhance methane production by creating anaerobic conditions that favor methanogenic microbes. This effect is particularly pronounced during the preparation of fields for crops such as rice, where waterlogged conditions are essential. Temperature also plays a role; warmer temperatures can accelerate microbial activity and organic matter decomposition, thus potentially increasing methane emissions. Effective irrigation management during this time can help mitigate excessive methane production by avoiding overly saturated soil conditions.

In the growing season, adequate rainfall is essential for crop growth, but excessive water can lead to conditions that support the anaerobic decomposition of organic matter, thereby increasing methane emissions. Conversely, insufficient rainfall might reduce methane emissions at the cost of increased crop stress and lower yields. Temperature influences are dual; higher temperatures increase microbial activity and organic decomposition rates, boosting methane emissions. However, plant physiological responses to higher temperatures can also alter root exudation patterns, potentially affecting soil microbial communities and their methane-producing capabilities. Managing these conditions through controlled irrigation and the selection of crops adapted to local climatic conditions can help reduce methane emissions.

In the harvesting season, the impact of rainfall is predominantly linked to the moisture content of the soil and crop residues. Wet conditions can slow the decomposition of organic material left in the field, temporarily reducing methane emissions. However, if these residues remain wet for prolonged periods, particularly in warmer conditions, they can become hot spots for methane production as they eventually decompose anaerobically. Temperature effects during harvesting are also significant, as warmer temperatures can increase the rate of residue decomposition, potentially leading to higher short-term methane emissions. Strategies such as timely harvesting to avoid rainy periods and managing residue treatment can effectively control methane outputs during this season.

Conclusion and Future Directions for Research

In this chapter, we address methane emission concentrations in Africa. We first present the results for the continental mean average of methane emissions, calculated for 2023. This average reveals a significant presence of methane emissions throughout the continent. The pronounced methane emissions from natural processes in almost all African countries is particularly striking, reaching its peak in the region of the Sahel. The analysis also indicates a number of discernible patterns, trends, and regional disparities.

We calculated the mean average methane emissions at a countrywide level to further investigate the disparities in methane emissions between countries. The results show that the amount of methane emitted varies significantly between different countries.

To assess the amount of methane emitted from the agricultural sector, we compared methane emissions from agricultural (cropland) and nonagricultural (non-cropland) land, focusing on areas characterized by natural processes. This comparison provides valuable insights into the relative contributions of different land use types to methane emissions, serving as a baseline reference for understanding the impact of human activities on methane production. The differences in methane emissions demonstrate the agricultural sector's significant contribution to methane emissions. The quantity of methane emitted was notably higher during certain months of the year.

We then introduced climatic variables to explore the possible correlation between methane emissions and changes in these variables throughout the year. Our findings indicate that temperature and rainfall significantly impact methane emissions. Additionally, we examined the relationship between the cultivation of specific crops, climatic variables, and methane emissions. We found that atmospheric methane levels vary according to the sowing, growing, and harvesting seasons, with more pronounced methane emissions during the harvesting season.

In this chapter, the use of TROPOMI primarily focuses on measuring methane emissions from natural processes, such as wetland emissions and agricultural activities, while not accounting for other significant sources of methane, such as industrial activities, waste management, and fossil fuel extraction. This limitation means the data presented do not capture the full spectrum of African methane emissions.

Future research should aim to investigate these additional sources of methane emissions to provide a more comprehensive assessment of Africa's net contribution to global methane emissions. By integrating data from other sources and measurement techniques, such as ground-based sensors, satellite data that can capture industrial emissions, and inventory methods, researchers can develop a more accurate methane budget for the continent. This expanded approach will be crucial for understanding the overall impact of African countries' emissions on global methane levels and for formulating effective mitigation strategies that address all significant sources of emissions.

CHAPTER 5

Climate Risks and Vulnerabilities in African Agrifood Systems

Sambane Yade, Khadim Dia, and Delia Grace Randolph

Introduction

In an era when the impacts of climate change are becoming increasingly pronounced, understanding and mitigating climate risk is paramount, especially for regions highly vulnerable to environmental change. Africa, with its rich biodiversity and varied climates, stands on the front line, facing unique challenges posed by climate change and climate variability. The continent's susceptibility around climate change is not just a matter of environmental concern but a multifaceted issue affecting socioeconomic development, agricultural sustainability, and the overall well-being of its inhabitants. The imperative to assess, comprehend, and adapt to these risks is more critical now than ever, necessitating a detailed analysis of various climate-related parameters and their long-term implications.

This chapter addresses climate change in African agrifood systems through the lenses of environmental changes, health outcomes, and household vulnerabilities. The overall objective is to provide a comprehensive overview of how climate change influences these interconnected domains, driving home the necessity for integrated and adaptive strategies. By exploring environmental indicators, health outcomes, and household vulnerabilities, the chapter aims to paint a holistic picture of the challenges and potential pathways to resilience.

The first section, Environmental Risks of Climate Change, focuses on how climate change alters key environmental parameters such as temperature, precipitation, and vegetation health. These changes have profound implications for Africa's ecosystems, affecting agricultural productivity, water resources, and overall environmental stability. This section aims to identify and analyze temperature anomalies, assess precipitation variability, evaluate vegetation health, and determine drought risks. By doing so, it seeks to inform and support the development of effective climate risk management and adaptation strategies.

The second section, Health Risks of Climate Change, examines the direct and indirect effects of climate change on human health. Africa's vulnerability to health impacts is significant, with climate-sensitive diseases and health conditions exacerbating the already high burden of disease. This section explores how climate change affects the epidemiology of infectious diseases, impacts noncommunicable diseases, and influences overall health determinants through environmental changes. By exploring these health risks, the chapter aims to contribute to the development of robust health systems and interventions that can mitigate the adverse effects of climate change on health.

The third section, Households' Vulnerability to Climate Change, evaluates the extent of households' vulnerability to climate change impacts in Africa using two case countries: Rwanda and Senegal. This section uses a composite vulnerability to climate change (VCC) index to assess household exposure, sensitivity, and adaptive capacity. By focusing on these dimensions, it highlights the differential impacts of climate change on various regions and communities, underscoring the need for targeted policies and adaptive measures. The analysis aims to provide examples of how to support the design and implementation of effective climate adaptation actions at the household level, thereby enhancing resilience.

In summary, this chapter aims to provide a detailed and integrated analysis of climate change impacts on Africa's environment, health, and households. The broader objective is to foster a deeper understanding of these interconnected issues and to support the development of comprehensive strategies that enhance resilience and sustainability across the continent. Through this exploration, we hope to contribute valuable insights and practical recommendations for policymakers, stakeholders, and communities facing the multifaceted challenges of climate change.

After the ratification of the Paris Agreement by African countries, expressing their strong political will to act on climate change, countries have also engaged to implement their nationally determined contributions (NDCs) and national adaptation plans (NAPs). The goals of the NAPs are to reduce vulnerability to the impacts of climate change by building adaptive capacity and to integrate adaptation into development policies and strategies. In this context, climate change vulnerability assessments will contribute to more efficient implementation of NAPs, which are essential tools for understanding the risks and opportunities associated with climate change, guiding adaptation efforts, and building climate resilience at the local, national, and global scales.

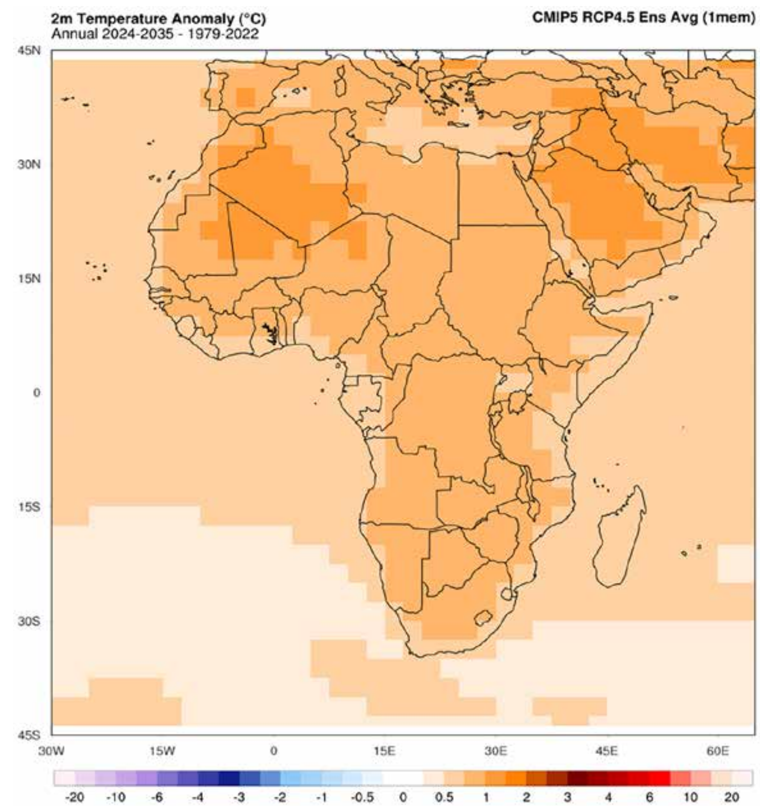
Environmental Risks of Climate Change

The primary objective of this section is to deepen our understanding of climate risk in Africa, with a focus on the implications of environmental changes and their potential impacts on the continent's ecosystems, socioeconomic development, and human well-being. By systematically assessing a range of environmental indicators, our study aims to achieve five specific objectives: First, it aims to evaluate the extent of land surface temperature (LST) variations across Africa by identifying regions that have experienced significant temperature changes compared to historical averages. This analysis will highlight areas most affected by warming trends, contributing to a broader understanding of climate change impacts. Second, the study seeks to assess precipitation variability by examining patterns over the continent to distinguish areas of rainfall deficiency or excess. This objective aims to shed light on the evolving dynamics of water availability, potential drought conditions, and their implications for agriculture and water resource management. Third, the study will evaluate vegetation health and coverage using normalized difference vegetation index (NDVI) data to identify regions with robust vegetation cover as well as areas facing vegetative stress. This aspect is crucial for understanding the impacts of climate variability on agricultural productivity and ecosystem resilience. Fourth, the study plans to determine drought risk and impact by employing a modified vegetation water supply index (MVWSI) for a detailed assessment of drought risk across various regions of Africa. By identifying drought-prone areas, this objective aims to inform strategies for drought mitigation and adaptation, with a particular focus on agricultural sustainability and food security. Finally, the study intends to provide actionable insights and data-driven recommendations for policymakers, stakeholders, and communities across Africa. By offering a comprehensive analysis of climate risks and their multifaceted impacts, the study supports the development of effective strategies for climate adaptation and resilience building.

Climate Projection and Implications in Africa

Figure 5.1 shows projected temperature anomalies for Africa based on the CMIP5 model ensemble under the RCP4.5 scenario. CMIP5 (Coupled Model Intercomparison Project Phase 5) compares climate models to assess future climate impacts (Taylor, Stouffer, and Meehl 2012). The RCP4.5 scenario assumes moderate emissions reductions, with greenhouse gas levels peaking around 2040 and a radiative forcing of 4.5 W/m² by 2100 (Thomson et al. 2011). The data also includes projections from Climate Reanalyzer, an online tool for visualizing climate datasets (Climate Reanalyzer 2024). It compares the expected annual temperatures for the period 2024–2035 with the historical baseline period of 1979–2022. The RCP4.5 scenario is a stabilization pathway that assumes some level of global mitigation efforts. Greenhouse gas emissions under this scenario peak around 2040 before declining. The radiative forcing is expected to reach 4.5 W/m² by 2100, leading to a moderate level of warming compared to more aggressive scenarios like RCP8.5. The map indicates widespread warming across the African continent. Temperature anomalies, which represent deviations from the historical average, are uniformly positive, signaling that temperatures are projected to increase throughout the continent. The color scale reveals that these anomalies range from about 0.5°C to over 3°C. Regions colored in darker

FIGURE 5.1—PROJECTION OF TEMPERATURE ANOMALIES FOR AFRICA



Source: Climate Reanalyzer (2024).

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shades of orange indicate more significant warming, particularly in the northern and eastern parts of Africa. The Sahara Desert and its surrounding regions exhibit some of the highest temperature anomalies, with values exceeding 3°C in some areas. This is consistent with the understanding that desert regions are particularly sensitive to changes in climate, often experiencing more extreme temperature shifts. The Horn of Africa and parts of the Rift Valley are also projected to see substantial warming, with anomalies likely exceeding 2°C. This region is already vulnerable to climate variability, and further warming could exacerbate issues related to water sufficiency, agriculture, and food security. While this region shows significant warming, the anomalies are generally less extreme than in the northern parts of the continent. However, even moderate increases in temperature could have profound effects on agriculture, biodiversity, and water resources in this region.

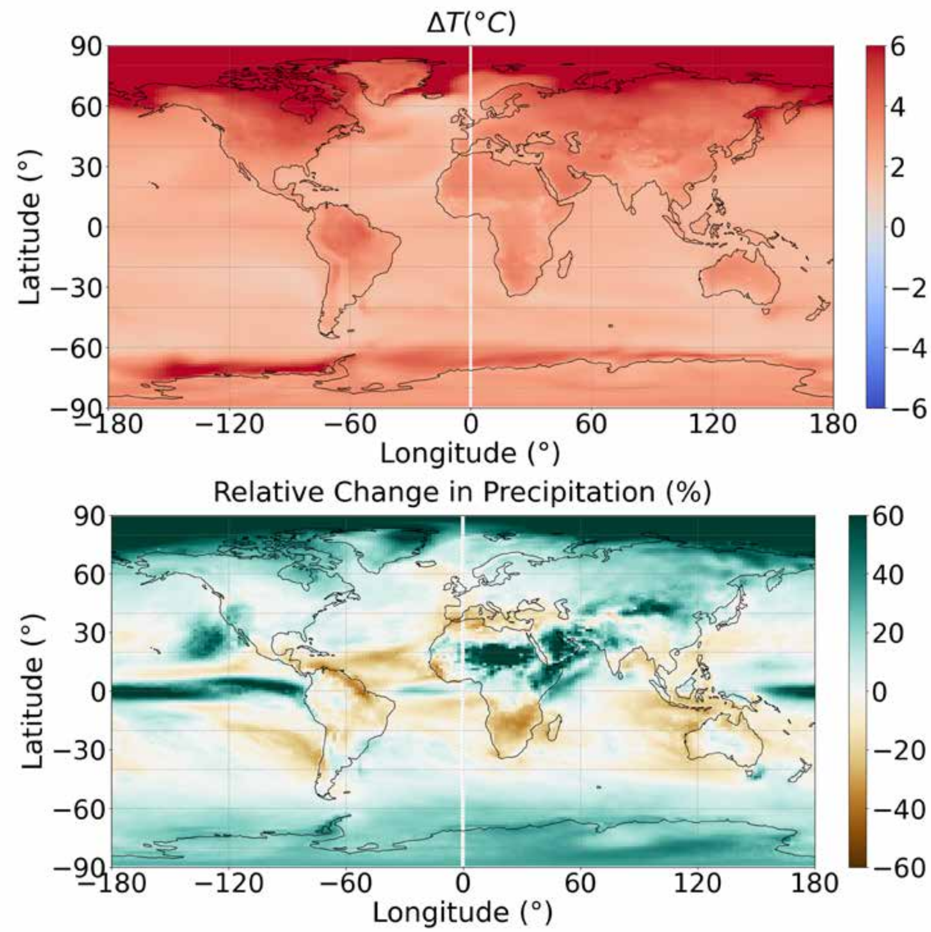
Under the RCP4.5 scenario, Africa is projected to experience significant warming, which could have far-reaching impacts on various sectors:

- **Agriculture:** Higher temperatures could reduce crop yields, increase evapotranspiration rates, and stress water resources, potentially threatening food security across the continent.
- **Water resources:** Changes in temperature and precipitation patterns could affect water availability, with regions already experiencing water stress likely to be most impacted.
- **Human health:** Increased temperatures can exacerbate health issues, particularly in vulnerable populations. Heat waves, vector-borne diseases, and food and water insecurity could all increase.
- **Biodiversity:** The warming temperatures could threaten biodiversity, particularly in ecosystems that are highly sensitive to temperature changes, such as savannas, wetlands, and coastal areas.

Figure 5.2 illustrates projected changes in temperature and relative changes in precipitation across the globe, with a specific focus on the African region. These projections are based on the CMIP6 (Coupled Model Intercomparison Project Phase 6) multi-model ensemble under the SSP2-4.5 scenario, which represents a medium-emission pathway associated with intermediate challenges in climate change mitigation and adaptation (Eyring et al. 2016; O'Neill et al. 2016).

The top panel of the map shows a significant increase in temperature across Africa, with the most pronounced warming observed in northern Africa and the Sahara region. This result aligns with findings that high-latitude and continental regions are expected to warm more rapidly than coastal and equatorial regions due to various factors, including the land–sea contrast and polar amplification

FIGURE 5.2—TEMPERATURE AND PRECIPITATION CHANGE PROJECTION ACROSS THE GLOBE FROM 2015 TO 2100



Source: Simulations from the CMIP6 models.

effects. The projected temperature rise in Africa is consistent across different regions, though the extent of warming varies, with the northern part of the continent experiencing some of the highest temperature increases. This heightened warming in northern Africa could exacerbate existing challenges related to water scarcity, agriculture, and human health.

The bottom panel of the map highlights changes in precipitation patterns, with notable drying trends in some regions of Africa, particularly in parts of southern Africa, while central and eastern Africa show potential increases in rainfall. The drying trends in southern Africa and the Mediterranean region are particularly concerning as they suggest an increased risk of drought, which could have severe implications for agriculture, water resources, and overall livelihoods in these regions. In contrast, the increase in precipitation in central and eastern Africa could lead to more frequent flooding events, posing risks to infrastructure and agriculture, and potentially leading to displacement of communities. The projected increase in temperatures and changes in precipitation patterns will likely exacerbate existing vulnerabilities in Africa, particularly in regions already prone to droughts or floods. Northern Africa's significant warming could lead to more intense heat waves and stress on water resources. At the same time, varying precipitation changes across the continent could complicate efforts to adapt to climate change, requiring region-specific strategies.

Incidence of Climate Risks in Africa

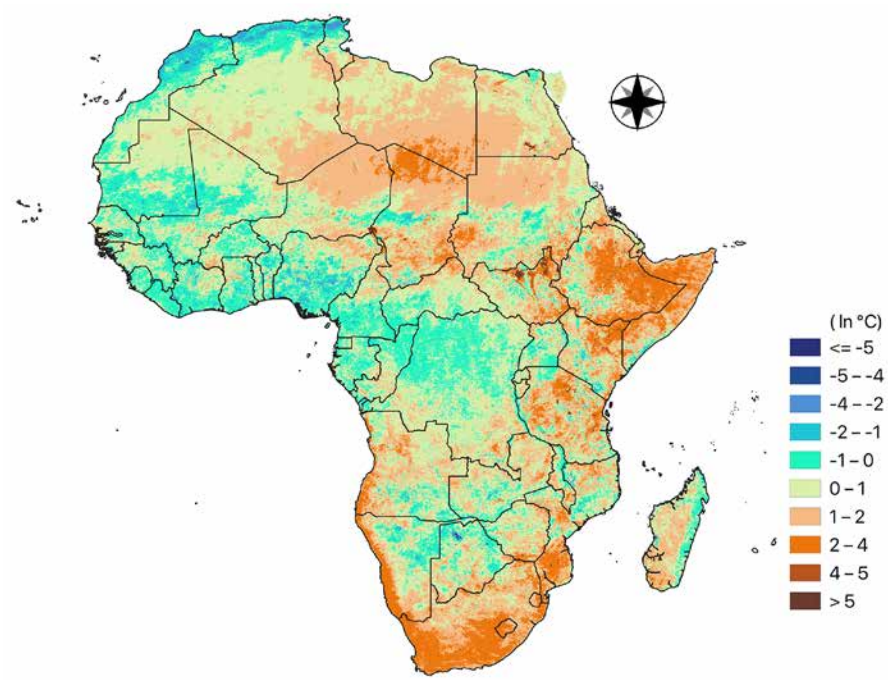
Our approach to analyzing climate risk involves a comprehensive examination of key environmental indicators that serve as proxies for understanding the broader impacts of climate change. Specifically, we focus on LST, precipitation anomalies, vegetation health as indicated by the NDVI, and drought conditions, each offering insights into different aspects of climate variability and its effects on the African continent. El Niño—since it causes changing patterns of both rainfall and LST—will also be discussed in this section.

Our analysis is underpinned by data from reputable sources, including the Moderate Resolution Imaging Spectroradiometer (MODIS) for Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) metrics (Justice et al. 2002; Didan 2015), and the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) database for precipitation data (Funk et al. 2015).The integration of these datasets, complemented by the application of the MVWSI for drought analysis, forms the backbone of our methodology, allowing for a nuanced understanding of climate risk in Africa. Through this multifaceted approach, we aim to contribute valuable insights into climate risk management and adaptation strategies suitable for safeguarding Africa's future against the adversities posed by climate change.

Land Surface Temperature

LST is a crucial indicator in Earth observation and climate science. LST is the temperature of the Earth's surface, which includes various types of land cover such as soil, vegetation, water bodies, and built-up areas. It is a significant parameter, providing valuable insights into surface temperature variations and environmental changes over time. In Figure 5.3 we have shown the difference

FIGURE 5.3—AFRICA 2023 LAND SURFACE TEMPERATURE DIFFERENCE FROM THE AVERAGE OF THE LAST 20 YEARS



Source: Data processing and map by authors, based on MODIS data.

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between LST in 2023 and the average LST over the last 20 years to capture temperature anomalies in Africa.

LST is a fundamental indicator of the Earth's surface condition and plays a pivotal role in the physical processes of the Earth's surface energy balance (Li et al. 2013). The analytical comparison of 2023 LST data with the 20-year historical average reveals pronounced thermal anomalies across Africa, with a significant uptick in temperatures across southern, eastern, northern, and selected western African nations. Such anomalies underscore the escalating concern over rising global temperatures and their direct and indirect impacts on ecosystems and human livelihoods (IPCC 2021).

The results reveal that in 2023, most of Africa recorded temperatures above the average for the period 2003–2022, except for the desert areas of northern Africa. The most significant temperature anomalies were recorded in southern Africa (Mozambique, Namibia, South Africa, Swaziland), eastern Africa (Djibouti, Ethiopia, Kenya, South Sudan, Sudan), northern Africa (Egypt, Libya), and some western African countries (Chad, Niger). The lowest temperature anomalies in 2023 are noted in countries in western, northwestern, and west-central Africa.

Precipitation Anomalies

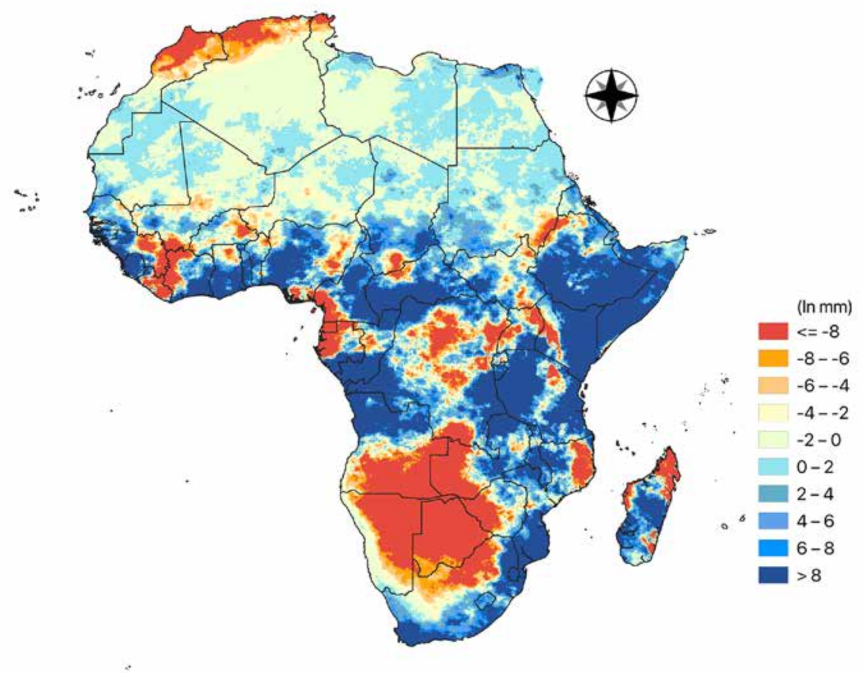
A precipitation anomaly is a deviation from the average or expected precipitation pattern for a given area over a certain period. Anomalies are characterized by above-average (excess) or below-average (deficient) precipitation in comparison to the long-term average. The rainfall anomaly between 2023 and the average of the last 20 years is computed using the CHIRPS datasets and shown in Figure 5.4. The results reveal two forms of rainfall anomaly in Africa. On the one hand, there is a sharp decrease in precipitation in 2023 on average, compared to the previous 20 years, in the northern African zone, in part of western Africa (Chad, Liberia, Mali, Mauritania, Niger) and in part of southern Africa (Angola, Botswana, Namibia, Zambia, Zimbabwe). On the other hand, rainfall anomalies exceeded the average for the period 2003–2023 in northeastern Africa, large parts of western Africa, the eastern Sahel region, Sudan, and parts of South Africa.

Vegetation Health

The NDVI is a widely used numerical indicator in remote sensing and vegetation studies. It quantifies the presence and health of vegetation by measuring the difference between near-infrared (NIR) and red-light reflectance from the Earth's surface. NDVI relies on the fact that healthy vegetation strongly absorbs red light (which is used in photosynthesis) and reflects NIR light. It is a significant parameter, providing valuable insights into vegetation dynamics, health, and distribution across different landscapes over time. Figure 5.5 shows the difference between NDVI in the current year (2023) and the average LST over the last 20 years to capture temperature anomalies in Africa.

The health and distribution of vegetation across Africa are critical indicators of ecosystem vitality. The NDVI, by quantifying the difference between NIR and visible light reflectance, offers insights into the health and stress levels of vegetation ecosystems. Our findings for 2023 indicate both robust and stressed vegetation zones, highlighting the need for targeted ecological management and conservation efforts (Pettorelli et al. 2005).

FIGURE 5.4—AFRICA 2023 RAINFALL DIFFERENCE FROM THE AVERAGE OF THE LAST 20 YEARS



Source: Data processing and map by authors, based on CHIRPS datasets.

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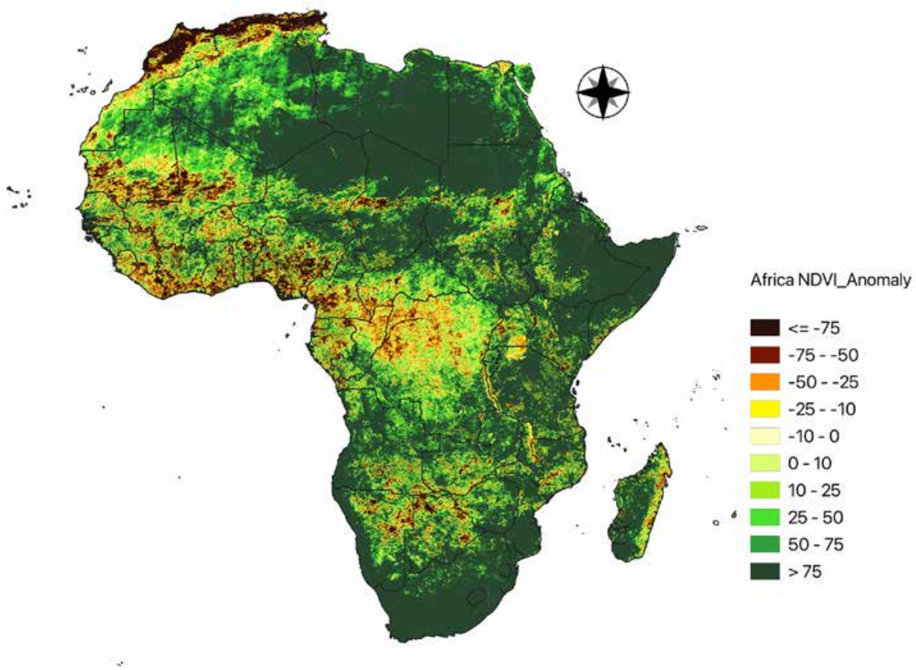
FIGURE 5.5—AFRICA 2023 NORMALIZED DIFFERENCE VEGETATION INDEX ANOMALY



Source: Data processing and map by authors, based on MODIS datasets.

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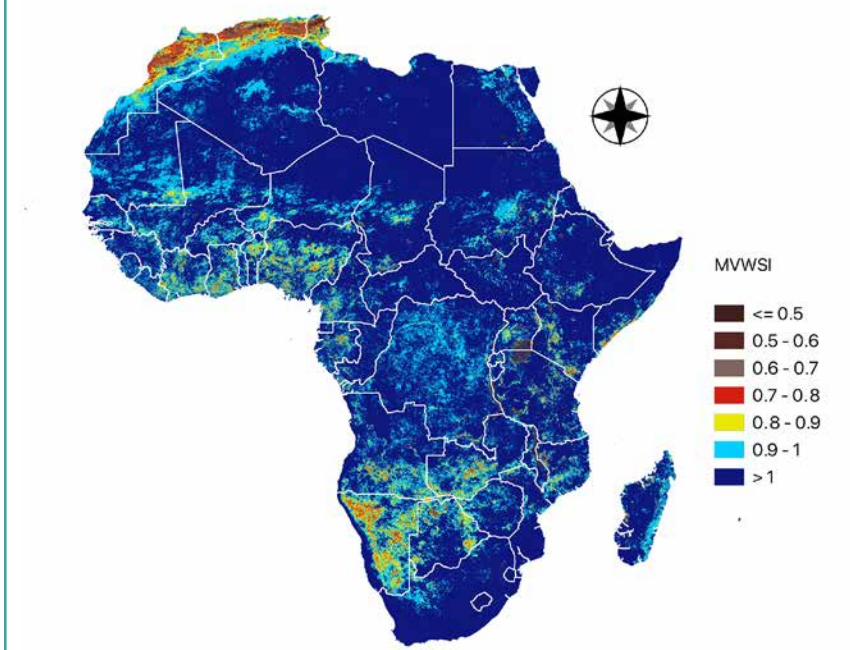
FIGURE 5.6—AFRICA 2023 MODIFIED VEGETATION WATER SUPPLY INDEX



Source: Data processing and map by authors, based on MODIS datasets.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

Figure 5.5 offers insight into the anomalies in vegetation cover between 2023 and the average of the preceding 20 years. The findings indicate that in regions such as northeastern Africa, eastern Africa, and a significant portion of southern Africa, there are no noticeable deviations in vegetation cover for the year 2023. Conversely, the data also uncover anomalies in the Horn of Africa and across a vast expanse of western Africa, highlighting areas where vegetation cover significantly diverges from historical norms.

Agricultural Drought Risk

Drought, characterized by extended periods of dry weather, leads to severe water shortages that adversely affect lives, assets, and livelihood activities (World Bank 2017). Such conditions have been notably detrimental in western Africa, where they exacerbate natural resource scarcity, diminish agricultural yields, and trigger crop failures, escalating food prices, hunger, and malnutrition (UNDRR 2021). The World Bank (2017) delineates drought into four distinct types: meteorological, hydrological, agricultural, and socioeconomic, each defined by its specific impact parameters. Our study focuses primarily on agricultural drought, which is assessed through soil moisture levels. For this purpose, we employ the modified vegetation water supply index (MVWSI) , conceived by Wu and Lu (2016) as a tool for agricultural drought risk and mitigation analysis. The MVWSI scale, when ranging from 0 to 1+, serves to identify areas at risk of drought; a lower MVWSI indicates reduced vegetation water supply, signifying more severe drought conditions. Conversely, MVWSI values exceeding 1 denote regions unaffected by drought. Droughts significantly undermine water security, agricultural productivity, and overall livelihood sustainability. Through the lens of the MVWSI, our 2023 analysis identifies critical regions across western Africa, southern Africa, and northern Africa. These findings underscore the urgent need for robust water management and drought resilience strategies to mitigate the adverse effects of these conditions (Wu and Lu 2016).

The MVWSI classification primarily focuses on agricultural drought, which is why much of Africa where agriculture is less prominent is not marked as drought-prone. In contrast, other maps highlight regions like the Sudano-Sahelian belt where agriculture is central, showing these areas as highly drought-prone. The difference lies in the specific focus—general aridity versus agricultural vulnerability.

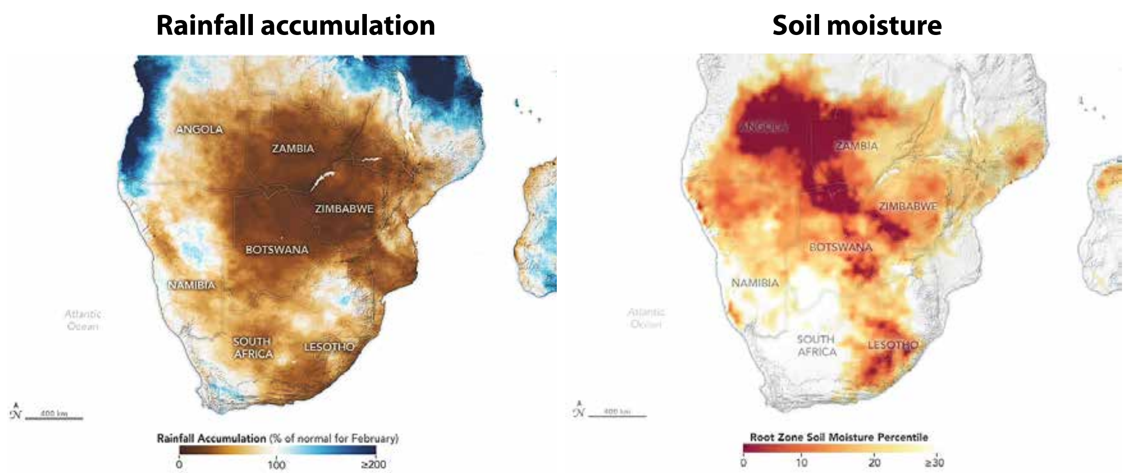
Figure 5.6 illustrates widespread areas characterized by dark blue hues, indicating MVWSI values greater than 1 across nearly all surveyed countries, suggesting these regions are currently not experiencing drought. Nonetheless, areas within western Africa, Namibia in southern Africa, and significant portions of northern Africa (Morocco, Tunisia) are identified as drought-prone, necessitating vigilant monitoring and the implementation of preemptive drought mitigation measures.

El Niño and La Niña Effects

El Niño is part of a natural climatic phenomenon called the El Niño–Southern Oscillation, which originates from a temperature anomaly in the surface waters of the South Pacific. When this is particularly marked and positive (at least +0.5°C), there is an El Niño episode; in the opposite case (a significant heat deficit), it is called the La Niña phenomenon. These two opposing states both significantly alter global weather patterns. During the onset of El Niño, the surface waters of the tropical Pacific Ocean, which are warmer, release more moisture and heat into the atmosphere, which usually leads to a rise in global temperatures. For example, 2016 was the hottest year on record and was a year marked by El Niño. However, the regional effects of the phenomenon remain variable and complex, with some places being both warmer and cooler than expected at different times of the year (Gaudiaut 2023).

In 2024, southern Africa has been experiencing one of its most severe droughts in recent decades, largely driven by an intense El Niño event. This drought has had devastating impacts on agriculture, food security, and livelihoods across the region. Figure 5.7 reveals that the El Niño phenomenon has led to a significant reduction in rainfall across southern Africa, particularly during the crucial months of December 2023 to February 2024. This period is typically when the region receives most of its annual rainfall, which is essential for the growth of rainfed crops like maize. The lack of sufficient rainfall has directly impacted soil moisture levels, which are crucial for crop growth and agricultural productivity. Figure 5.7 shows the soil moisture conditions as of March 2024, emphasizing the areas most severely affected by the drought. As shown in the map, the soil moisture levels across much of southern Africa are critically low, particularly in key agricultural zones. This situation has led to a drastic reduction in crop yields, especially for maize, which is a staple food for millions of people in the region (The United Nations in South Africa 2024).

FIGURE 5.7—RAINFALL ACCUMULATION AND SOIL MOISTURE CONDITIONS IN SOUTHERN AFRICA (FEBRUARY–MARCH 2024)



Source: NASA Earth Observatory (2023).

Health Risks of Climate Change

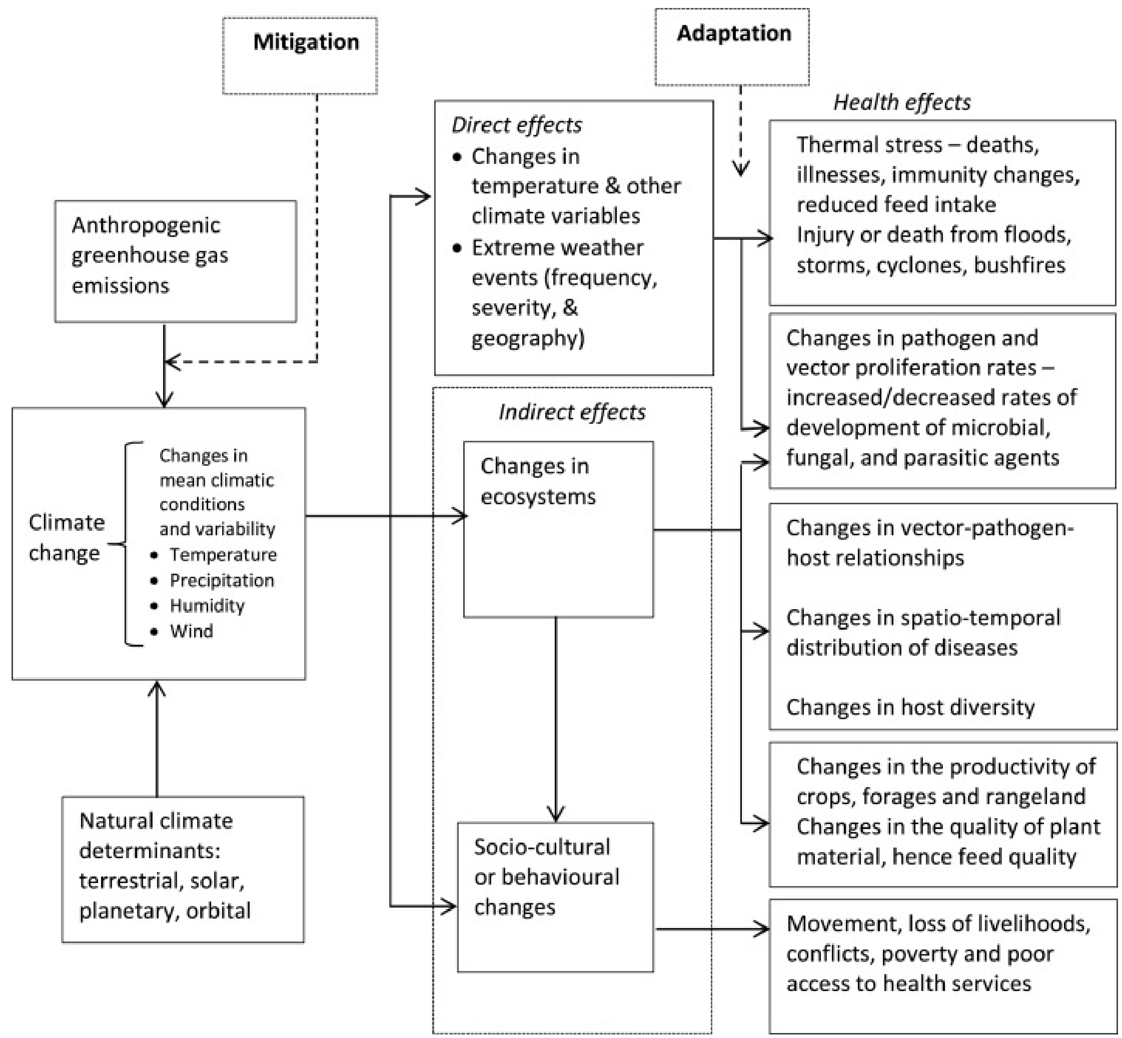
Connections Between Climate and Health

Worldwide, climate change poses a significant threat to the health and well-being of humans, animals, and ecosystems. Africa is the continent with the highest vulnerability to climate change overall and specifically to the health impacts of climate change (Birkmann et al. 2022). Nearly two-thirds (63 percent) of the countries most vulnerable to the health impacts of climate change are in Africa, with Burundi, Eritrea, Ethiopia, Gabon, Madagascar, and Niger at particularly high risk (World Bank 2017). As well as impacts on human health, climate change affects the health of animals, plants, soils, and ecosystems. The One Health (OH) approach provides a conceptual framework for both understanding and addressing the vulnerabilities around climate change by recognizing the intrinsic connections between human, animal, and environmental health.

The OH approach has been defined as "an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems… The approach mobilizes multiple sectors, disciplines, and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for healthy food, water, energy, and air, taking action on climate change, and contributing to sustainable development" (Mettenleiter et al. 2023, 3). This approach has been endorsed by the Quadripartite.[1]

The pathway through which climate change impacts health can be conceptualized as follows: climate hazards lead to landscape changes, which in turn affect various

FIGURE 5.8—PATHWAYS THROUGH WHICH CLIMATE CHANGE IMPACTS ONE HEALTH



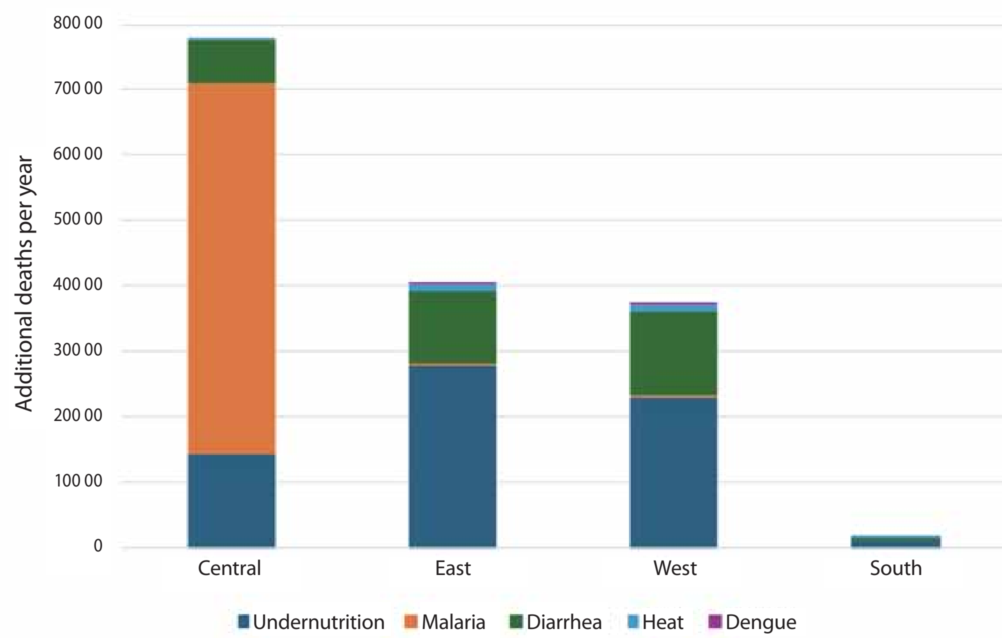
Source: Bett et al. (2017).

1 The OH Quadripartite is composed of the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), and the World Organisation for Animal Health (WOAH).

health determinants, ultimately resulting in health outcomes. Climate hazards such as rising temperatures, changes in precipitation patterns, and extreme weather events can cause landscape changes like deforestation, desertification, soil erosion, and habitat loss. These landscape changes can then influence health determinants, including air quality, water availability, food security, and the spread of disease vectors (Bett et al. 2017). Ultimately, these changes in health determinants can lead to adverse health outcomes for humans, animals, and plants as shown in Figure 5.8.

Between 2030 and 2050, climate change is predicted to cause a million extra deaths every six years in Africa south of the Sahara (SSA) (Figure 5.9); these are preventable (WHO 2014). More recently, global mortality has been modeled under various socioeconomic futures that incorporate varying approaches to climate change and mitigation (Sellers 2020). Sustainable development is the most optimistic future, where challenges to mitigation and adaption are low; in this scenario, mortality in Africa is lower than in the more pessimistic scenarios (regional rivalry and inequality) (Sellers 2020).

FIGURE 5.9—EFFECTS OF CLIMATE CHANGE ON SELECTED CAUSES OF DEATH IN AFRICA SOUTH OF THE SAHARA, 2020–2030



Source: Authors, adapted from WHO (2014).

Climate-Sensitive Diseases

The epidemiology, or pattern, of climate-sensitive infectious diseases (CSIDs) changes as the result of climate-induced changes in the environment, especially in rainfall and temperature (Omazic et al. 2019). Reviews find that 50 to 60 percent of human and animal infectious diseases are climate-sensitive (McIntyre et al. 2017; Mora et al. 2022). CSIDs can be categorized by transmission pathways, the most important being vector-borne, waterborne, and foodborne (Cissé, Menezes, and Confalonieri 2018). Many zoonotic diseases are climate-sensitive. Climate also affects noncommunicable diseases (NCDs) by affecting the social and environmental determinants of health.

Vector-borne diseases

For vectors such as mosquitoes, ticks, and flies, warmer is better, and vector-borne diseases (VBDs) are often considered the most important category of CSID. Climate change is already creating favorable conditions for the breeding and survival of mosquito species that transmit important human diseases in Africa including malaria and arboviruses (dengue, chikungunya, yellow fever, and West Nile) (Thomson et al. 2018). The last three listed diseases were all first identified in Africa. Malaria is the most important human VBD in Africa, and climate change is predicted to increase transmission in the East African highlands and shift the malaria epidemic fringe southward (Caminade, McIntyre, and Jones 2019).

The two most important livestock VBDs are African animal trypanosomiasis (AAT), transmitted by tsetse flies, and East Coast fever (ECF), transmitted by the brown ear tick (Okello et al. 2022). Warmer temperatures could enable tsetse expansion into new areas, including the East African highlands, while conversely, population growth and agricultural development may reduce tsetse habitats in other regions. Similarly, ECF's vector, the brown ear tick, may decline in some western arid regions due to rising temperatures but may expand its range into cooler highland areas with increased rainfall (Bett et al. 2017).

Waterborne Diseases

Waterborne diseases are caused by pathogens such as bacteria, protozoa, and viruses transmitted through water; these include cholera, amoebiasis, hepatitis, and schistosomiasis. In Africa, where conducive factors often coincide, water-related diseases cause over 10 percent of infant mortality, which is 25 times higher than in developed countries (Ligtvoet et al. 2018). Cholera is one of the most climate-sensitive diseases and has been increasing in range and incidence in recent years. In 2023, 19 African countries reported outbreaks causing a quarter of a million cases and thousands of deaths (Africa CDC 2024).

Foodborne Diseases

Only recently has it been recognized that the burden of foodborne diseases (FBDs) is comparable to that of malaria, HIV and AIDS, or tuberculosis and that the highest per capita burden occurs in Africa (Havelaar et al. 2015). The 2023 Annual Trends and Outlook Report estimated that 160 million FBD episodes and 210,000 FBD deaths occurred in Africa in 2023 (including northern Africa); most of these are preventable (Ayalew, Kareem, and Grace 2023). Climate change can also impact food safety and increase the risk of FBD. Higher temperatures and changes in precipitation patterns can facilitate the growth of harmful pathogens, such as mycotoxins, in food crops (Jagger et al. 2016).

Noncommunicable Diseases

Infectious diseases still dominate the burden of disease in SSA, but a demographic transition is leading to the increased importance of noncommunicable diseases (NCDs), which predominate in high-income regions, with cardiovascular disease followed by cancers as the two leading causes (Gouda et al. 2019). The link between climate change, agrifood systems, and NCDs is becoming increasingly evident (Nugent and Fottrell 2019).

One of the most important NCDs in Africa is malnutrition. Children whose weight is too low for their height are said to be affected by wasting, and children whose height is too low for their age are affected by stunting. Although progress has been seen over the last decade, 150 million children were stunted in 2022, nearly half of them (43 percent) in Africa, where progress on stunting is lagging most (UNICEF, WHO, and WB 2023). Climate change impacts stunting by reducing crop yield and animal productivity and by increasing disease and extreme events (Agostoni et al. 2023).

The psychological impacts of disasters may exceed the physical effects of the injuries they cause (Hayes et al. 2018). There have been few studies on climate change and mental health in Africa, but effects have already been seen on African cultural heritage markers such as historic buildings, archaeological sites and museum collections, seasonal festivals, sacred sites, traditional fishing practices, and traditional crops and foodways (Atwoli, Muhia, and Merali 2022). Higher rates of substance misuse have been reported among people displaced and exposed to extreme climate stressors in South Africa (Myers et al. 2011).

Climate-Related Health Shocks and Emergencies

Public Health Emergencies

Africa reports the heaviest burden of public health emergencies globally, experiencing an average of around 100 emergencies each year, almost all due to infectious diseases (Koua et al. 2023). These include emerging diseases and diseases associated with extreme events. Around 30 percent of public health emergencies are due to zoonoses (including COVID-19), and zoonotic public health emergencies are increasing over time (Koua et al. 2023). As well as infectious diseases, extreme weather events have direct and indirect impacts on public health. An investigation by Carbon Brief (Dunne 2023) found that at least 15,700 people were killed by drought, heat wave, cyclone, flood, and landslide in Africa in 2023 and a further 34 million were adversely affected. CSIDs are often triggered by extreme climatic events. A comprehensive review found most outbreaks followed floods (38 percent) or tropical cyclones (26 percent), with fewer following drought, heavy rainfall, or heat waves (Alcayna et al. 2022).

Emerging Infectious Diseases

Emerging diseases have been of great concern over the last several decades following pandemics caused by COVID-19, avian influenza, and other diseases. Considering CSID, western Africa is an emerging hotspot for dengue (Badolo et al. 2022), and chikungunya is predicted to expand into central Africa (Tjaden et al. 2017).

Health Impacts Associated With Extreme Events

Flooding accounts for nearly half (47 percent) of all recorded natural disasters and is responsible for nearly half (44 percent) of the deaths from disasters (UN 2015; UNEP 2020). A recent review of flood-associated disease in SSA found that around 40 million people were affected by floods between 2010 and 2020; this has been linked to enormous spikes in cholera, increased risk of scabies, increased prevalence of arboviruses (chikungunya, dengue), and more diagnosed cases of malaria (Suhr and Steinert 2022). Even without flooding, extreme precipitation events have been consistently associated with waterborne disease outbreak events (Semenza 2020). In addition to diseases, floods cause drowning, trauma, hypothermia, and food insecurity from loss of crops and animals.

Climate change contributed to the recent deadly drought in the Horn of Africa, which left more than 20 million people facing food insecurity and more than 5 million children facing acute malnutrition, while also decimating the livestock on which communities depend (WFP 2023). Droughts also cause decreased river flows, which in turn increase the concentration of waterborne pathogens, leading to unclean water and disease.

Households' Vulnerability to Climate Change

The aim of this section is to provide a household vulnerability assessment to support the design and implementation of ongoing climate adaptation actions through prioritization of the most affected areas and households. To this end, we first explain the methods used to estimate vulnerability to climate change at the household level using the Intergovernmental Panel on Climate Change (IPCC) framework, and then we present two case studies, from Rwanda and Senegal.

Methods of Estimating Households' Vulnerability to Climate Change

A climate vulnerability assessment is an extension of a climate impact assessment that evaluates the potential effects of one or several climate change scenarios on one or more impact domains and compares them to projected effects of a constant climate. We distinguish between two generations of climate vulnerability assessments. The first-generation vulnerability assessment is characterized primarily by the evaluation of climate impacts in terms of their relevance for society and by the consideration of potential adaptation. The second-generation vulnerability assessment is the more thorough assessment of the adaptive capacity of people, thus shifting the focus from potential to feasible adaptation. Therefore, the second generation of climate vulnerability assessments emphasize vulnerability with three components: exposure, sensitivity, and adaptation capacity.

The *exposure* of a system to climate change refers to the magnitude of climatic variations that the system is expected to face. Thus, it depends on the level of global climate change and, due to the spatial heterogeneity of anthropogenic climate change, on the system's location. Burton (1997) suggests a hierarchy of weather and climate phenomena (denoted as type 1, 2, and 3 variables) to distinguish between single climate variables (such as local temperature), specific weather events (such as a convective storm), and long-term processes (such as anthropogenic climate change). Which of these aspects are included in the exposure definition of a particular vulnerability assessment depends on its specific circumstances. The *sensitivity* of a system refers to the degree to which a system may be affected by exposure to climate change risks. It denotes the (generally multifactorial and dynamic) dose–response relationship between its exposure to climatic stimuli and the resulting impacts. *Adaptive capacity* refers to the ability of a system to adjust to climate change. Brooks (2003) classifies factors that determine adaptive capacity as either climate hazard-specific or generic and either endogenous or exogenous. Generic determinants of adaptive capacity in social systems comprise such nonclimatic factors as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit and Pilifosova 2003; Yohe and Tol 2002). Endogenous factors are the characteristics and behaviors of the subject population group, whereas exogenous factors include the wider economic and geopolitical context.

In terms of empirical estimations, the composite household vulnerability indicator is guided by the conceptual framework of climate-related risks contained in the (IPCC 2014) report which explores the potential impacts of climate change on agriculture and food security (Adger 2006; O'Brien et al. 2007; Sharma and Ravindranath 2019). The IPCC defines vulnerability as the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014). In line with this definition, household vulnerability at each administration level of a given country is estimated by calculating the administration-level score, I, for each of the three dimensions (exposure, sensitivity, and adaptation capacity). Subsequently, these dimension scores are summed up to obtain the overall VCC index. The results obtained from this estimation are used to compare and assess household vulnerability to climate change across the spatially disaggregated administrative units of the country.

Specifically, the VCC is estimated using the following formula:

$$\boldsymbol{VCC_i = \frac{1}{3}(Exposure\ score_i + Sensitivity\ score_i - Adaptation\ capacity\ score_i)},$$

$$\text{where} \begin{cases} \text{Exposure score}_i = \frac{1}{n_E}\sum_{k=1}^{n_E} V_{k,i}^{\text{Exposure}} \\ \text{Sensitivity score}_i = \frac{1}{n_S}\sum_{k=1}^{n_S} V_{k,i}^{\text{Sensitivity}} \\ \text{Adaptation capacity score}_i = \frac{1}{n_{IA}}\sum_{k=1}^{n_{IA}} V_{k,i}^{\text{Adaptation capacity}} \end{cases}.$$

Index $\boldsymbol{i}$ represents the administration level; $\boldsymbol{n_E}$, $\boldsymbol{n_S}$, and $\boldsymbol{n_{IA}}$ correspond to the number of select variables for each dimension. $\boldsymbol{V_{k,i}}^{\boldsymbol{Exposure}}$ corresponds to the $\boldsymbol{k^{th}}$ normalized variable of the region $\boldsymbol{i}$ for the exposure dimension.

In addition to estimating the composite indicator, one can analyze the vulnerability level of each administration level according to two categories. The first category is called "relative" (see Figure 5.10) and helps to compare and prioritize the districts of the country and to distinguish within an administration level which districts are "much more vulnerable," "more vulnerable," "less vulnerable," and "much less vulnerable" than others. The second category is called "absolute," as it helps to compare the VCC index across countries or over years.

Case Study 1: Households' Vulnerability to Climate Change in Rwanda

For the case of Rwanda, we have estimated the composite VCC index using household data collected by the National Institute of Statistics of Rwanda (NISR) in 2021, under the Comprehensive Food Security and Vulnerability Analysis (CFSVA) survey. Results of the VCC index, shown in Figure 5.11, reveal that the overall level of household vulnerability in Rwanda is 0.43 on a scale of 0 to 1 (the closer the value is to 1, the higher the vulnerability level). This score is largely attributable to the inability of households to adapt to climate shocks (0.61), followed by their exposure to climate change risks (0.38), and finally the level of household sensitivity (0.29). These results indicate that although the level of sensitivity is somewhat low, households in Rwanda have a high exposure to climate change risks and limited capacity to adapt to adverse effects. The major source of vulnerability among households in Rwanda is their limited adaptive capacity to climate shocks, indicating that policy actions should focus on strengthening this factor.

Figure 5.11 shows that Karongi, Nyaruguru, and Gisagara were the three districts with the largest share of vulnerable households among all districts in 2021, as they recorded scores that ranged between 0.53 and 0.56. These three

FIGURE 5.10—CATEGORIZATION OF VULNERABILITY

Relative categorization: k-means approach

The k-means clustering algorithm is a technique used for partitioning a dataset into a predetermined number of clusters. The Steps for the k-means method:

- Step 1: Randomly select *k* initial cluster centroids (points in the feature space). These centroids represent the initial cluster centers.
- Step 2: Assign each data point to the nearest cluster centroid based on a distance metric, commonly the Euclidean distance. Each data point is assigned to the cluster whose centroid is closest to it.
- Step 3: Recalculate the cluster centroids by taking the mean of all data points assigned to each cluster. This moves the centroids to the center of their respective clusters.
- Step 4: Iterate steps 2 and 3 until convergence is reached, typically when the cluster assignments no longer change or when a specified number of iterations is reached.
- Step 5: Once convergence is achieved, the final clustering is obtained. Each data point belongs to the cluster associated with the nearest centroid.

As results, we will obtain the four following clusters:

Much more vulnerable

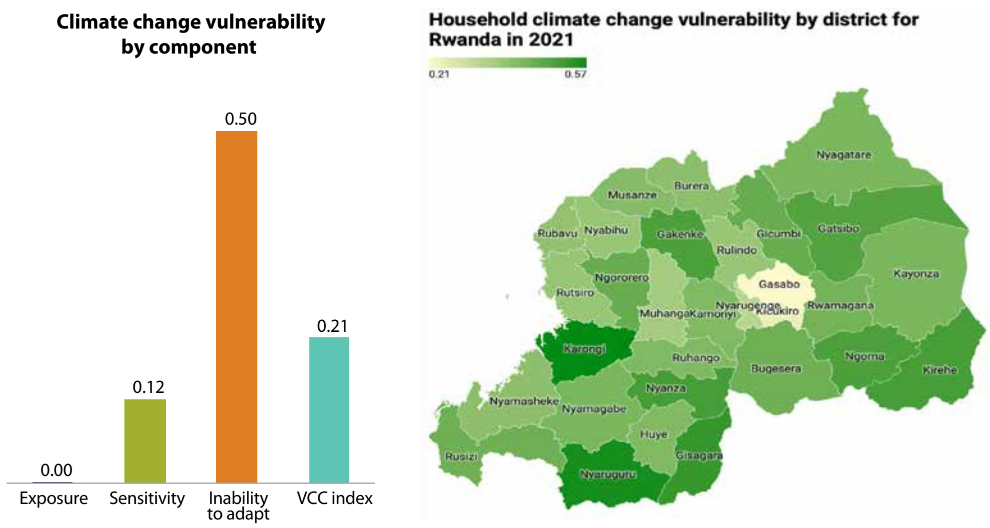
More vulnerable

Less vulnerable

Much less vulnerable

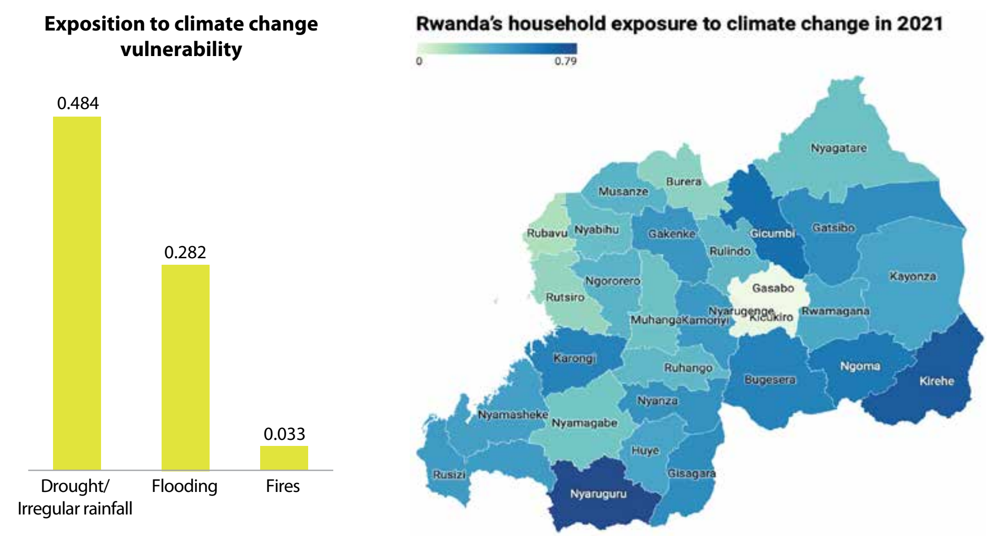
Source: Authors' compilations.

FIGURE 5.11—RWANDA'S HOUSEHOLD VULNERABILITY TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using the 2021 CFSVA data (NISR 2023).

FIGURE 5.12—RWANDA'S HOUSEHOLD EXPOSURE TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using the 2021 CFSVA data (NISR 2023).

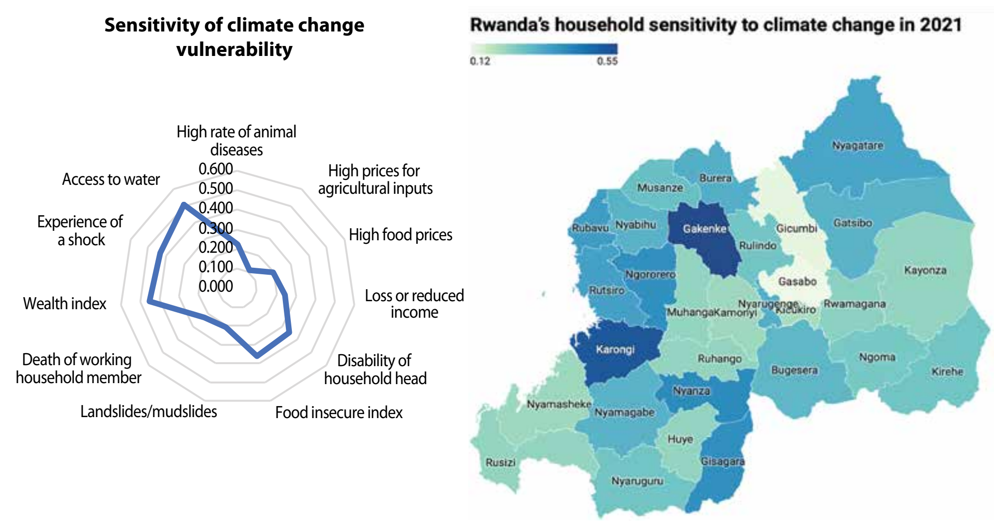
were followed by Kirehe, Nyanza, Gakenke, and Ngoma, which all recorded scores above 0.5. The two districts with the fewest vulnerable households are Gasabo (0.21) and Kicukiro (0.24), which are both located in Kigali province. This indicates that households in urban areas are less vulnerable to climate change than rural households, as they have options for income diversification, as well as better access to markets and public services. The other districts have a medium level of vulnerability, with scores ranging between 0.38 and 0.49.

At the national level, the results shown in Figure 5.12 reveal that heavy rainfall as well as frequency and intensity of flooding are the variables that most explain the exposure of households to climate change risks, while fire plays a minor role. The results show that households in the districts of Nyaruguru, Kirehe, Gicumbi, Ngoma, Karongi, Bugesera, Gisagara, and Gatsibo face high exposure to climate change risks, which is reflected in their scores, all above 0.5. Households in the districts of Gasabo, Kicukiro, Nyarugenge, Rubavu, Rutsiro, Burera, Nyamagabe, and to a lesser extent, Nyagatare and Muhanga, have the lowest exposure to climate change risks, with scores of under 0.3. Households residing in the other districts are moderately exposed to climate change risks.

The results of the sensitivity analysis, presented in Figure 5.13, show that households in Gakenke and Karongi districts are the most sensitive to climate change risks, with scores over 0.5. In contrast, the districts of Gasabo, Gicumbi, Kicukiro, Kamonyi, Nyamasheke, Ruhango, Kayonza, Rusizi, Muhanga, Huye, and Rwamagana have the lowest scores, as does Ngoma to a smaller extent. Households in the other districts are moderately sensitive to climate change risks. The sensitivity of households to climate change risk is mainly associated with low access to water. Other associated variables are low wealth index scores, experiences of shocks, and food insecurity.

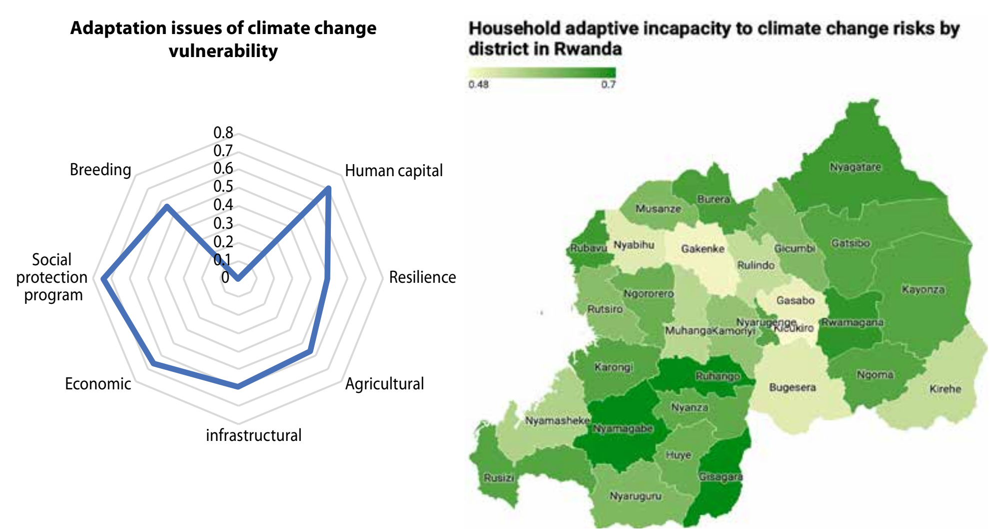
Regarding households' adaptation capacity, the results shown in Figure 5.14 reveal that households in the districts of Gisagara, Nyamagabe, and Ruhango have the highest incapacity (that is, the lowest capacity) to adapt to climate change, with a score equal to 0.70. This interpretation remains valid for households in the districts of Rwamagana (0.68), Rubavu (0.67), Nyagatare (0.67), Burera (0.66), Gatsibo (0.65), Kayonza (0.65), Rusizi (0.65), Nyarugenge (0.65), Ngoma (0.65), and Karongi (0.65). Kicukiro and Gakenke districts have the

FIGURE 5.13—RWANDA'S HOUSEHOLD SENSITIVITY TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using the 2021 CFSVA data (NISR 2023).

FIGURE 5.14—RWANDA'S HOUSEHOLD ADAPTATION CHALLENGES TO CLIMATE CHANGE IN 2021



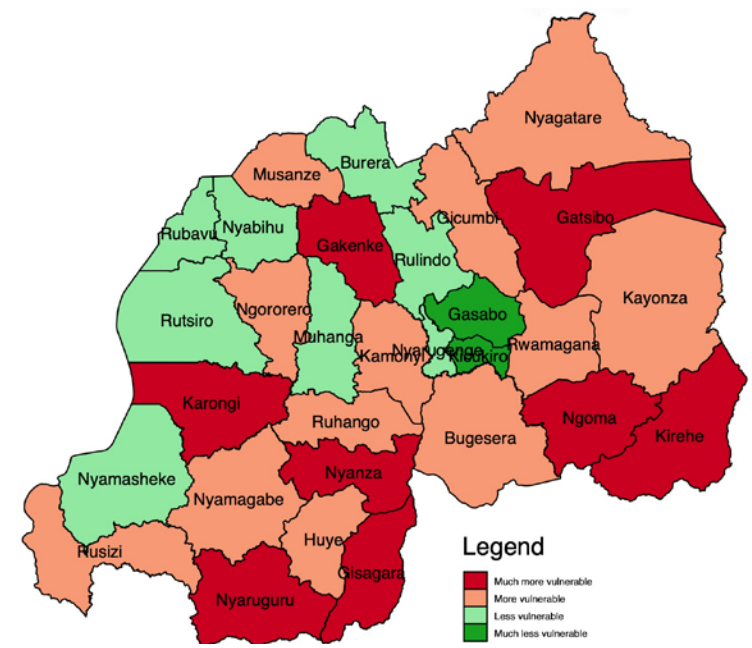
Source: Authors' calculations using the 2021 CFSVA data (NISR 2023).

lowest scores for this dimension among all the districts. This means that households in these two districts have greater capacity to adapt to climate change shocks than households in other districts.

In terms of the seven subdimensions used to calculate this score, low access to social protection programs (0.74), limited human capital (0.70), and low income level (0.66) best explain the inability of households to adapt to climate change. The human capital score is generally attributable to the low levels of membership in any association or cooperative, limited weather and climate information, and lack of training and technical assistance in improved agricultural and livestock practices.

Figure 5.15 shows the results of relative categorization. Relative categorization helps to compare and prioritize the districts of the country. The results reveal that Gasabo and Kicukiro districts have the greatest share of households in the "much less vulnerable" category in Rwanda in 2021.

FIGURE 5.15—CATEGORIZATION OF HOUSEHOLDS' VULNERABILITY IN RWANDA'S DISTRICTS IN 2021



Source: Authors' calculations using the 2021 CFSVA data (NISR 2023).

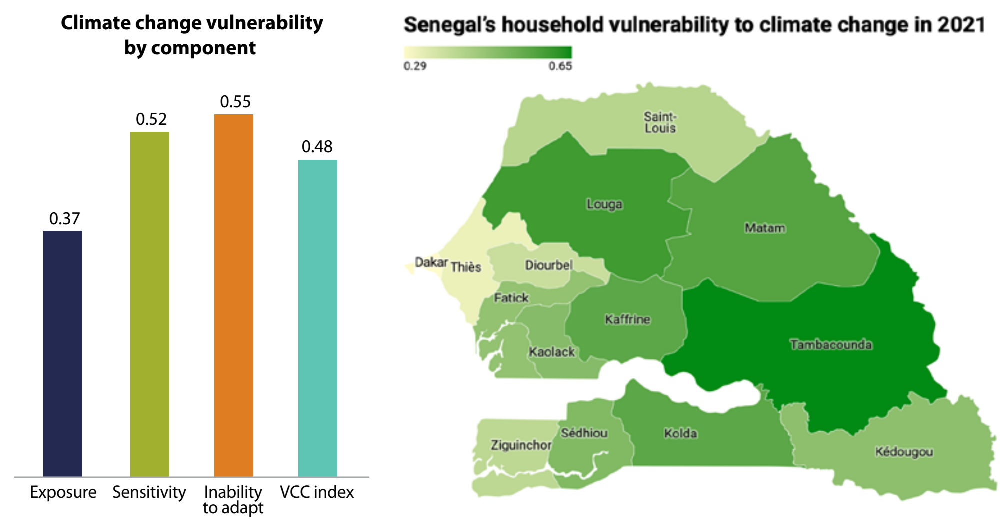
Burera, Rutsiro, Nyamasheke, Rubavu, Muhanga, Rulindo, and Nyabihu have the greatest share of "less vulnerable" households in 2021. Gatsibo, Ngoma, Kirehe, Nyanza, Nyaruguru, Gisagara, Karongi, and Gakenke have the greatest share of "much more vulnerable" households, and the remaining districts have the greatest share of "more vulnerable" in 2021 based on the results of the VCC index.

Case Study 2: Households' Vulnerability to Climate Change in Senegal

For the case of Senegal, the VCC index results, shown in Figure 5.9, reveal that the overall level of household vulnerability is 0.48 on a scale of 0 to 1 (the closer the value is to 1, the higher the vulnerability). The composite VCC index is explained more by the inability of households to adapt (0.57), followed by their sensitivity to climate change (0.49) and, finally, their level of exposure (0.37). The result indicates that though the level of exposure is somewhat low, households in Senegal are very sensitive to any climate risk exposure and have very limited capacity to adapt to the adverse effects. Looking at Figure 5.16, we note that the Tambacounda region stands out as the most vulnerable region, with a score of 0.65. It is followed by Louga, Matam, Kolda, Kaffrine, and Sédhiou, with scores above 0.5. The two regions with the least vulnerable households are Dakar (0.29) and Thiès (0.32), indicating that households in urban areas are less vulnerable to climate change than rural households, as they have options for income diversification and better access to markets and public services. The other regions have a medium level of vulnerability, with scores ranging between 0.38 and 0.49. Beyond these results, this section has shown how each of the three dimensions of vulnerability evolves simultaneously in each region.

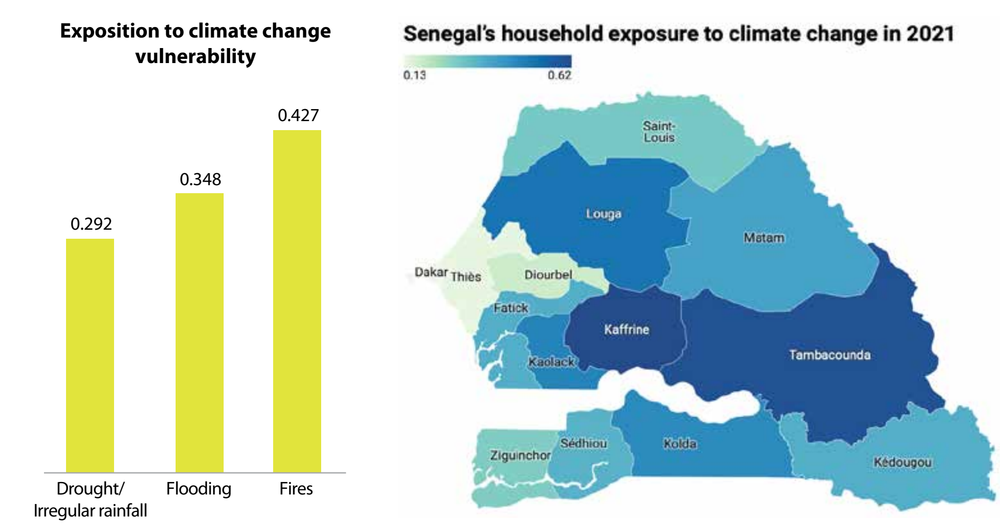
In view of the results shown in Figure 5.17, we note that households residing in the regions of Tambacounda, Kaffrine, and Louga are very exposed to climate change because they have scores above 0.5. Households in the regions of Dakar, Thiès, Diourbel, Ziguinchor, and to a lesser extent, Saint-Louis are the least exposed to climate change, with scores under 0.3. Households residing in other regions of Senegal are moderately exposed to climate change. The exposure dimension was computed based on four variables: precipitation, drought/irregular rainfall, flooding, and fires. At

FIGURE 5.16—SENEGAL'S HOUSEHOLD VULNERABILITY TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using data from EHCVM and DAPSA.

FIGURE 5.17—SENEGAL'S HOUSEHOLD EXPOSURE TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using data from EHCVM and DAPSA.

the national level, the results show that heavy rainfall and the frequency and intensity of fires better explain the exposure of households to climate change than do flooding and drought/irregular rainfall.

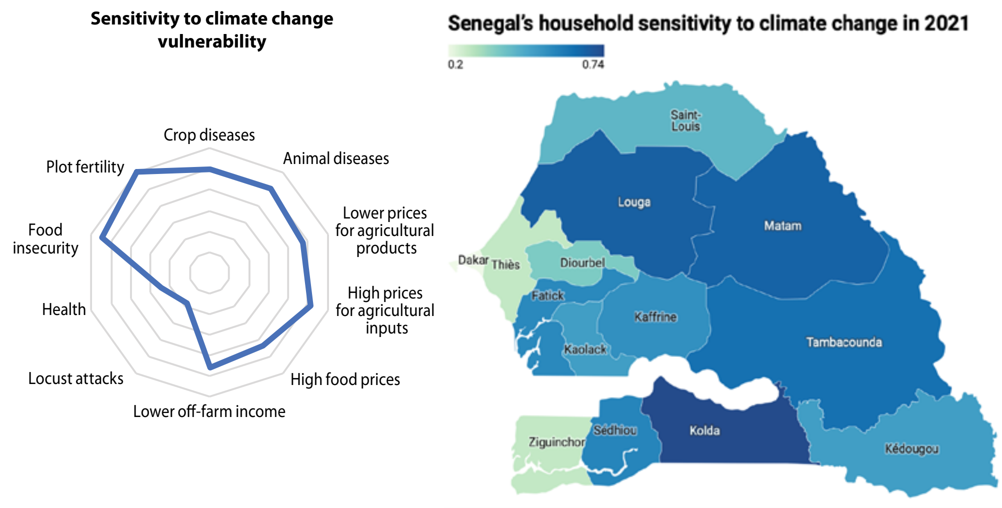
The results of the sensitivity dimension, presented in Figure 5.18, reveal that households in the Kolda region are the most sensitive to climate change risks, with a score of 0.74. Households in Louga (0.68), Matam (0.67), and Tambacounda (0.63) are also very sensitive to climate change. In the regions of Sédhiou, Fatick, and Kaffrine, scores vary between 0.54 and 0.57, also reflecting the sensitivity of their households. The lowest scores are obtained in Dakar, Thiès, Ziguinchor, and to a lesser extent, Diourbel. The sensitivity of households to climate change is mainly associated with the low incidence of irrigated cultivation by farmers. Added to this are the infertility of cultivated areas, a high demographic dependency rate, food insecurity, high prices for agricultural inputs, animal diseases, and crop diseases.

The results in Figure 5.19 reveal that households residing in the Tambacounda region have the lowest capacity (that is, the highest incapacity) to adapt to climate change, with a score of 0.71. The index score is also higher in the regions of Matam (0.66), Ziguinchor (0.65), and Louga (0.62), which means that households in these regions have low capacity to adapt to climate change. The regions of Kolda and Kaffrine have the lowest scores in this dimension. This means that households in these two regions have more capacity to adapt to climate change than households in other regions of Senegal. Regarding the four subdimensions that we defined to calculate the scores, low agricultural performance (0.66) and limited human capital (0.58) best explain the inability of households to adapt to climate change.

The highest score in agriculture is explained by the low share of households who used or practiced improved seed variety, animal or household waste, inorganic fertilizer, and multiple cropping or irrigated plots. The inability of households to adapt to climate change through the human capital subdimension is generally explained by a very low levels of female entrepreneurship, household heads using agricultural information, households having processed agricultural products, and women with access to agricultural land, by region.

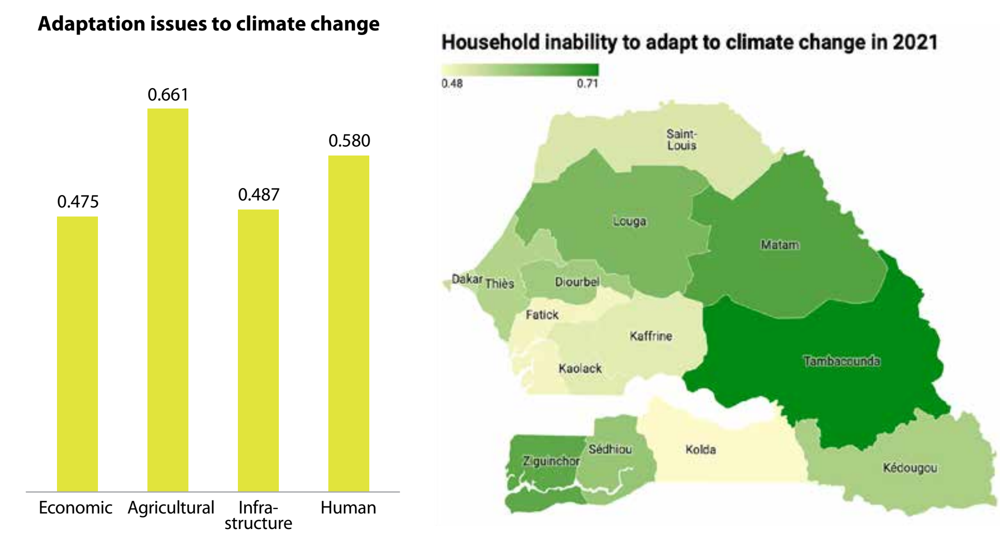
Figure 5.20 shows the results of relative categorization, which helps to compare and prioritize the regions of Senegal. The results reveal that the

FIGURE 5.18—SENEGAL'S HOUSEHOLD SENSITIVITY TO CLIMATE CHANGE IN 2021



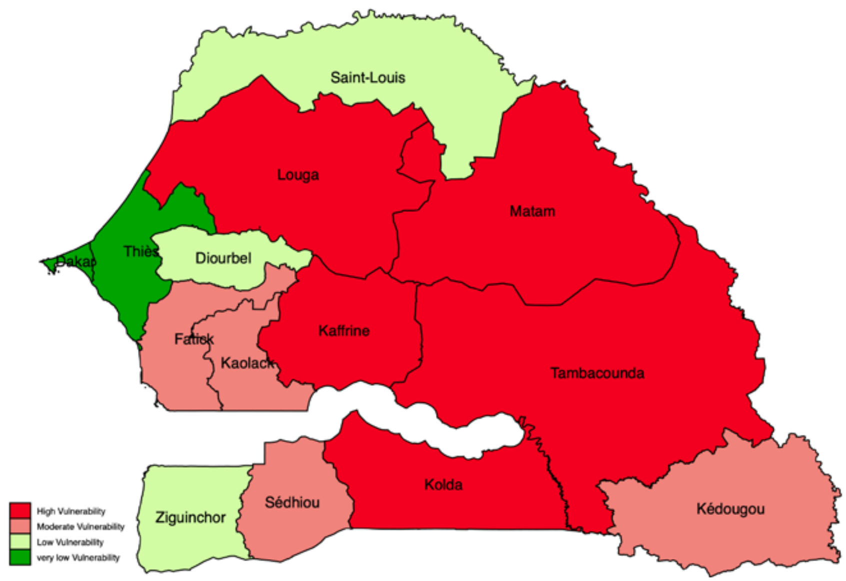
Source: Authors' calculations using data from EHCVM and DAPSA.

FIGURE 5.19—SENEGAL'S HOUSEHOLD ADAPTATION CHALLENGES TO CLIMATE CHANGE IN 2021



Source: Authors' calculations using data from EHCVM and DAPSA.

FIGURE 5.20—CATEGORIZATION OF HOUSEHOLDS' VULNERABILITY IN SENEGAL'S REGIONS IN 2021



Source: Authors' calculations using data from EHCVM and DAPSA.

regions of Matam, Louga, Kaffrine, Tambacounda, and Kolda have a higher incidence of households with VCC scores in the "much more vulnerable" category than those in other categories in 2021. Fatick, Kaolack, Sédhiou, and Kédougou have a higher share of "more vulnerable" households. The central western part of the country (Dakar and Thiès) has a greater share of "much less vulnerable households" than other categories. Finally, the regions of Saint-Louis, Diourbel, and Ziguinchor have a higher proportion of "less vulnerable" households.

Conclusion and Policy Recommendations

This chapter addresses climate change in African agrifood systems through the lenses of environmental changes, health outcomes, and household vulnerabilities. The insights gained from this research are vital for policymakers, stakeholders, and communities as they help to identify priority risks and sources of vulnerability to climate change across communities and at the household level.

The analysis of environmental risks associated with climate change in Africa reveals significant and varied impacts across the continent, highlighting several critical areas requiring immediate attention and strategic intervention. The evaluation of LST data indicates a notable increase in temperatures across various regions, particularly in southern, eastern, and parts of western Africa. These temperature anomalies underscore the urgent need for policies aimed at mitigating the effects of rising temperatures, which threaten both ecosystems and human livelihoods. Precipitation anomalies, identified through the CHIRPS dataset, reveal areas with significant deviations from historical rainfall patterns. The assessment of vegetation health using the NDVI shows regions with both robust and stressed vegetation. The MVWSI, used to focus on agricultural drought risk, reveals critical areas at risk of drought. All of this analysis shows that climate change poses a significant threat to the health and well-being of humans, animals, and plants worldwide.

The impacts of climate change on health are multifaceted, ranging from the increased prevalence of infectious diseases and NCDs to the direct impacts of climate shocks and disasters. Africa is the continent most vulnerable to climate change and its health impacts, with 63 percent of the most at-risk countries located there, including Burundi, Eritrea, Ethiopia, Gabon, Madagascar, and Niger. CSIDs, which account for 50 to 60 percent of human and animal diseases, are primarily transmitted through vectors, water, and food. Climate change is expected to cause 1 million additional deaths every six years in SSA between 2030 and 2050. The continent faces the highest global burden of public health emergencies, mainly due to infectious diseases, with around 100 emergencies annually. Floods affected about 40 million people in SSA between 2010 and 2020, while recent droughts in the Horn of Africa have severely impacted food security, affecting more than 20 million people and leading to increased waterborne diseases due to reduced river flows and unclean water.

The chapter also sheds light on vulnerability to climate change using case studies from two countries (Rwanda and Senegal). We believe that climate change vulnerability assessments of these countries will contribute to making the implementation of NAPs more efficient by answering these three questions: Who is vulnerable? To what? Where? The assessments are made following the standardized method developed by the IPCC. The results of the household vulnerability assessment reveal that the overall level of household vulnerability in Senegal in 2021 is 0.48 while it is 0.43 for Rwanda (the closer the value is to 1, the higher the vulnerability level). In these two countries, the inability to adapt to climate change is the dimension that most explains the vulnerability, followed by the sensitivity dimension for Senegal and the exposure dimension for Rwanda.

The following policy recommendations are drawn from the three analyses presented above:

- The temperature anomalies underscore the urgent need for policies aimed at mitigating the effects of rising temperatures, which threaten both ecosystems and human livelihoods.
- The variability in precipitation is a precursor to potential drought conditions, impacting water availability and agricultural productivity. The findings emphasize the necessity for adaptive water resource management and the implementation of drought-resistant agricultural practices.
- The NDVI highlights the dynamic nature of vegetation response to climatic variations and the importance of targeted conservation and land management strategies to sustain agricultural productivity and ecosystem health.
- The MVWSI indicates a pressing need for comprehensive drought mitigation strategies, particularly in western Africa and parts of southern and northern Africa. Ensuring food security and sustainable agricultural practices in these regions is paramount to mitigating the adverse effects of drought conditions.
- Addressing the complex challenges posed by climate change to health requires integrated OH policies that consider the interconnections between climate change, agriculture, and health. These policies should prioritize the development of climate-resilient agrifood systems and health adaptation strategies to enhance the resilience of communities and safeguard human, animal, and plant health. Central to the OH paradigm is multisectoral collaboration and community participation to facilitate the exchange of knowledge, resources, and best practices, ensuring that policies and interventions are tailored to the specific needs and contexts of different regions and communities.
- Well-functioning surveillance systems and timely responses may reduce the cost of disease outbreaks by 95 percent (Grace 2014). Many African countries lack capacity to detect disease, especially in livestock and wild animals. Several important zoonotic outbreaks have been discovered only when humans have died, although they must have already caused animal deaths. There are human, livestock, wildlife, and plant surveillance systems in Africa, but they are both siloed and underfunded. Investment in improving and integrating surveillance could have large benefits in the control of CSIDs.
- While much information exists on the impact of climate on human, animal, and plant health in Africa, it is mostly drawn from one-off studies using various methodologies, covering various areas and times. Given the enormous impact of different climate and health problems, and the possible synergies from tackling them in a coordinated way, there would be much value in an integrated dashboard to track and report annually all climate-driven sickness and death in people, livestock, and plants.
- Collaborative efforts involving policymakers, researchers, healthcare professionals, and local communities are crucial for developing effective policies and interventions that can mitigate the impacts of climate change and improve health outcomes globally.
- For each African country, a representative sample of all households is needed. This database should contain data about households' perception of climate shocks (drought/irregular rainfall, flooding, heavy rainfall) in recent years. Second, the database must inform researchers about households' sensitivity to these shocks as well as their adaptation strategies.
- The two case studies, for Rwanda and Senegal, reveal that household vulnerability is largely attributable to the inability of households to adapt to climate shocks. This result indicates a strong need for targeted interventions to build adaptive capacity. Adaptive capacity is a functional transformation that involves the use of available opportunities more effectively and efficiently. For example, farm households may have access to irrigation, but unless they use it effectively, their adaptative capacity does not change. Similarly, while farmers may have access to weather and climate information, they remain vulnerable to climate shocks if they do not use this information in their decision-making. Efforts to strengthen resilience should therefore focus on effective and efficient utilization of available opportunities and emerging options.

CHAPTER 6

The Impact of Climate Change on Agriculture

Timothy S. Thomas

Introduction

Agriculture is an extremely important sector for Africa, providing a large contribution to GDP in most countries and, more importantly, representing a key source of employment in most of the continent—including 52 percent in Africa south of the Sahara in 2022 (International Labour Organization 2024)—while also serving as a bulwark against household food insecurity. Agriculture, however, is the sector most exposed to climate risk, and in years when climate conditions are not favorable, the resulting lower-than-normal agricultural production contributes to increases in food insecurity in almost every country on the continent.

Climate change is disrupting historical climate patterns, potentially worsening productivity in many locations and also potentially increasing the variability of seasonal precipitation. Changes in rainfall patterns could result in longer droughts or more frequent and severe flooding in addition to increased unpredictability. Longer droughts cause consecutive low-production years and can also impact hydroelectric power generation. Floods can wash away or inundate crops and can also wash away roads and bridges, disrupting market connections for farmers.

Higher temperatures associated with climate change can drive down yields in places where the temperature is already at or above the optimal temperature for the crops grown there, through direct, abiotic impacts on crop growth and through biotic impacts, with pests and diseases potentially causing both pre- and postharvest losses. Higher temperatures can also lower the productivity of labor devoted to agriculture, lower the productivity of livestock (meat, milk, and eggs), and increase livestock mortality and morbidity.

But despite its considerable potential harmful impacts, climate change could turn out to be relatively neutral or even positive in some locations, for several reasons. First, much agricultural activity occurs in cooler parts of countries, where rising temperatures could increase yields. Second, precipitation may increase in many locations, potentially enhancing yields where irrigation is not available and where rainfall has historically been less than optimal. Finally, while the theory is still scientifically controversial, many scientists believe that yields of C3 crops (all crops except the C4 crops: maize, sorghum, millet, teff, sugarcane, and some grasses) will benefit from higher levels of CO_2 in the atmosphere (commonly called "CO_2 fertilization"). C4 crops could potentially see very small boosts in yield from CO_2 fertilization.

This chapter examines the likely impact of climate change on African agriculture between now and 2050, presenting modeled results for the continent and the five subregions, drawing from crop and bioeconomic models that use multiple climate models as inputs. The chapter focuses on the impact of climate change on the major crops for the continent and each subregion. The second section briefly describes the models used in this chapter. The third section presents the key agricultural commodities for the continent and each subregion. The fourth section briefly describes Africa's climate along with the climate change that has been observed already. The fifth section provides the details of the climate models used. The sixth section focuses on the crop model results for Africa, showing the effect on seven different crops. The seventh section presents the results of the bioeconomic model, which considers how climate change affects other countries, in particular the comparative advantages of Africa under climate change. The final section provides concluding remarks.

Overview of Models Used in This Chapter

The description in this section draws on a similar description in Thomas and Robertson (2024), which focuses on eastern and southern Africa.

ISIMIP Climate Models

Every six to eight years, the Intergovernmental Panel on Climate Change (IPCC) produces a major synthesis of the current understanding of the science of climate change and the impact of climate change on the world. The latest iteration is known as the Sixth Assessment Report (AR6), a multivolume work whose first volume was published in 2021. As part of each assessment cycle, climate modeling teams from around the world produce their projections for future climates under specific greenhouse gas (GHG) emissions scenarios.

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) is an international network of modelers investigating the impact of climate change on multiple sectors. ISIMIP produces climate and socioeconomic datasets that can be used for consistent analysis across sectors. ISIMIP selected five of the climate models from those submitted for the IPCC's AR6 and downscaled them (Lange 2021) to half-degree pixels (approximately 50 kilometers on edge) that are useful for agricultural modeling. The climate models chosen by ISIMIP and AgMIP (the agricultural modeling group within ISIMIP) as representative models from CMIP6 (climate models from AR6) are GFDL-ESM4 (GDFL), IPSL-CM6A-LR (IPSL), MPI-ESM1-2-HR (MPI), MRI-ESM2-0 (MRI), and UKESM1-0-LL (UK).

The climate models are available for three different emissions scenarios, called representative concentration pathways (RCPs), designated by 2.6, 7.0, and 8.5, which represent the number of watts per square meter of radiative forcing in 2100 caused by GHGs in the atmosphere in 2100. This study focuses on the highest emissions scenario, RCP8.5, as an upper bound. Through 2050, it is very similar to RCP7.0, and therefore the modeling results are also similar (after 2050, the growth rate of GHGs under the RCP7.0 scenario tapers relative to that under RCP8.5).

DSSAT Crop Model

This study uses the Decision Support System for Agrotechnology Transfer (DSSAT) software to model the effect of climate on yields (DSSAT 2024; Hoogenboom et al. 2019; Jones et al. 2003). DSSAT is a well-documented and well-respected modeling tool. Aggregated monthly averages for a baseline climate of 2005 and future climates as projected by the five CMIP6 global climate models under RCP8.5 are input into the DSSAT weather simulator. The weather simulator generates daily weather consistent with the defined monthly climate aggregate. Multiple simulated daily weathers are generated at each pixel, yields are computed for them, and then the yields are averaged across the multiple simulations to generate the yield that is typical for that pixel and crop under that climate. DSSAT yields and yield changes are mapped and examined for geographic and quantitative consistency and smoothness. The simulation uses the resolution of the climate datasets. That is, the crop model makes projections for yield impact at every half-degree pixel, which is the standard resolution for most global studies of climate impact on agriculture. Calibration of yield levels is not necessary because the analysis considers yield changes over time due to climate change and not absolute values. Seven crops are modeled in the DSSAT: maize, sorghum, rice, groundnuts, wheat, soybeans, and potatoes.

IMPACT Bioeconomic Model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which has been used since the mid-1990s to study future global supply, demand, and trade in the agriculture and food sector, has climate change embedded as a fundamental component. Details of the model can be found in Robinson and colleagues (2024). IMPACT is a multimarket partial equilibrium model that solves for global prices that equate supply and demand for every year and commodity in the model. Production is computed at the level of IMPACT's food production units, which are the intersection of regions (which are, in most cases, countries) and major water basins. IMPACT has 159 regions and 154 water basins, which combine for 320 food production units. IMPACT has 62 commodities, including 39 crops, 6 types of livestock, and 17 processed foods. IMPACT solves for annual prices for 2005 through 2050.

IMPACT uses the DSSAT crop model results for the seven crops identified above and projects those results onto crops not directly modeled using a formula found in Robinson and colleagues (2024). IMPACT uses other models as well, such as water models, that draw on the same climate input data to inform IMPACT on hydrology, water basin management, and water stress. IMPACT generates projections for population growth, GDP growth, changes in consumer demand, and productivity growth due to agricultural progress in both seed technology and farm management. These projections help IMPACT model the changes in global demand and supply that determine global prices and therefore influence what producers choose to produce and what households choose to consume. This chapter focuses on IMPACT model outputs for harvested area, yield, and production.

An earlier version of IMPACT was used to produce a three-volume study on climate impact on agriculture in Africa (Hachigonta et al. 2013; Jalloh et al. 2013; Waithaka et al. 2013).

The Major Agricultural Commodities by Region

Table 6.1 shows the major crops of Africa and each of the five subregions. Western Africa accounts for 47 percent of the cultivated area in Africa, so it dominates the totals for the continent. Because there are important differences among the regions, each is presented separately, as well. For the continent as a whole, we see that four of the top five crops (by harvested area) are cereals, with cassava being the only noncereal. The top five crops represent 45 percent of the harvested area of the region.

Maize represents almost 15 percent of the continent's harvested area, being the number one crop in all subregions except northern Africa, where it ranks eighth. In southern Africa, maize represents a third of all harvested area, though maize area has been decreasing there over the last 20 years (FAO 2022). In eastern Africa, maize represents a fifth of all harvested area, and its area has been increasing by 3.1 percent per year. Similarly, maize represents slightly more than a fifth of all harvested area in central Africa, and maize area has been increasing at a whopping rate of 4.8 percent per year. Even in western Africa, where only 11 percent of the cultivated area is dedicated to maize, the harvested area has been growing at 4.2 percent per year over the last 20 years.

For the continent overall, maize yields are small relative to those of major producers such as the United States and Brazil. Nevertheless, yield has been growing at an impressive rate of 0.9 percent per year over the last 20 years, led by eastern and southern Africa, with the growth rate for both at or above 2.0 percent per year. The combination of yield and area growth has led to a 3.6 percent per year increase in the production of maize in Africa, with western, central, and eastern Africa all growing at 5.2 percent or more per year.

Rather than discussing every major crop in Africa, we shift our attention to the major crops in Africa and its subregions that have had very fast rates of production growth over the last 20 years. The fastest rate of growth indicated in Table 6.1 is 7.8 percent per year for sesame seed in northern Africa. This includes a 4.9 percent per year growth in harvested area and a 2.8 percent per year growth in yield. Second highest is teff in eastern Africa, with production growing at a rate of 6.6 percent per year—4.4 percent yield growth and 2.2 percent area growth. Rice production is expanding rapidly in central Africa, at 6.5 percent per year, while beans are expanding rapidly in southern

TABLE 6.1—LEADING CROPS IN AFRICA AND EACH SUBREGION BASED ON HECTARES HARVESTED IN 2020, AND GROWTH RATES 2000–2020

Crop	Rank, 2020	% of all area	Harvested area (000s hectares), 2020	Yield (tons/hectare), 2020	Annualized % change, 2000–2020		
					Harvested area	Yield	Production
All of Africa							
All crops		**100.0**	**286,761**	**n.a.**	**2.3**	**n.a.**	**n.a.**
Maize	1	14.5	41,605	2.06	2.7	0.9	3.6
Sorghum	2	9.8	28,162	1.01	1.2	0.8	2.0
Cassava	3	7.7	22,011	8.64	3.6	0.1	3.7
Millet	4	7.0	20,129	0.72	0.0	0.3	0.4
Rice	5	6.0	17,281	2.11	4.2	−0.3	3.9
Northern Africa							
All crops		**100.0**	**44,524**	**n.a.**	**1.9**	**n.a.**	**n.a.**
Sorghum	1	17.1	7,614	0.7	1.9	−0.4	1.5
Wheat	2	16.0	7,123	2.67	0.3	2.0	2.3
Sesame seed	3	11.1	4,937	0.3	4.9	2.8	7.8
Olives	4	10.7	4,760	1.12	3.8	1.0	4.8
Groundnuts	5	7.5	3,333	0.95	3.9	1.2	5.2
Western Africa							
All crops		**100.0**	**134,263**	**n.a.**	**2.5**	**n.a.**	**n.a.**
Maize	1	11.0	14,704	1.72	4.2	1.1	5.3
Sorghum	2	10.5	14,121	0.96	0.8	0.4	1.2
Millet	3	10.3	13,813	0.73	−0.3	−0.1	−0.4
Cowpeas	4	9.4	12,563	0.58	1.9	2.7	4.6
Rice	5	8.4	11,335	1.84	5.0	0.5	5.6
Central Africa							
All crops		**100.0**	**32,851**	**n.a.**	**3.6**	**n.a.**	**n.a.**
Maize	1	21.1	6,930	1.07	4.8	0.5	5.3
Cassava	2	20.4	6,705	8.44	3.9	0.5	4.4
Groundnuts	3	6.8	2,246	0.98	2.6	0.8	3.4
Sorghum	4	6.4	2,090	1.08	3.2	1.5	4.7
Rice	5	5.9	1,944	1.01	6.2	0.3	6.5
Eastern Africa							
All crops		**100.0**	**50,281**	**n.a.**	**2.5**	**n.a.**	**n.a.**
Maize	1	20.2	10,169	2.36	3.1	2.0	5.2
Beans	2	8.5	4,287	0.99	2.1	2.2	4.4
Sorghum	3	7.4	3,696	1.84	1.4	3.2	4.6
Teff, etc.	4	6.4	3,218	1.80	2.2	4.4	6.6
Cassava	5	6.2	3,138	5.70	4.2	−1.9	2.3
Southern Africa							
All crops		**100.0**	**24,842**	**n.a.**	**0.8**	**n.a.**	**n.a.**
Maize	1	33.5	8,328	2.64	−0.2	2.1	1.8
Rice	2	8.0	1,997	2.25	1.6	0.8	2.4
Cassava	3	6.2	1,545	11.99	−0.4	3.3	2.9
Beans	4	5.7	1,410	0.54	7.6	−1.3	6.2
Groundnuts	5	5.4	1,346	0.59	2.2	−0.6	1.6

Source: FAO (2022).

Note: n.a. = not applicable. Values for 2020 are based on the three-year average for 2018–2020. Starting period values for 2000 are based on the three-year average for 1998–2000.

Africa. Of the major crops included in the table, millet in western Africa has seen decreasing production over the past 20 years, at a rate of 0.4 percent per year, with both area and yield trending downward.

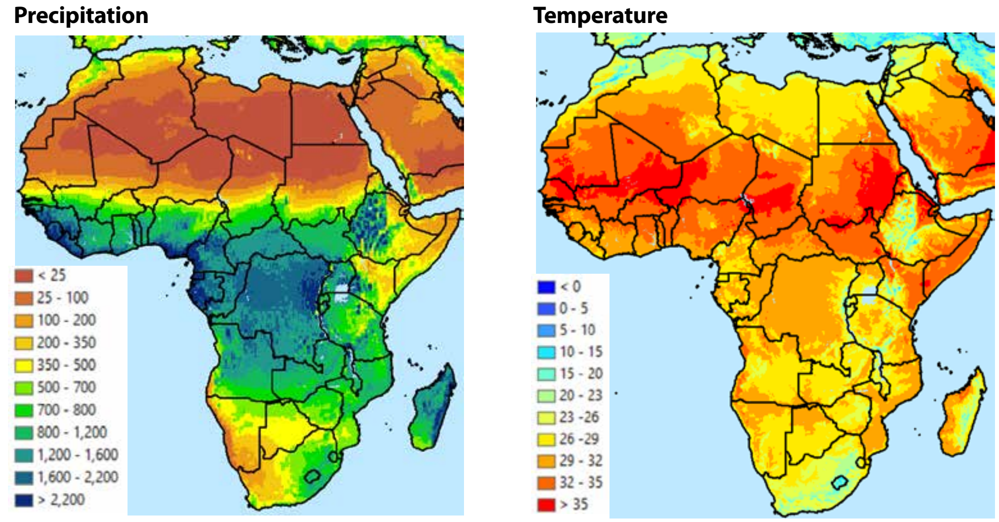
Millet in western Africa is not the only major crop showing negative yield growth in the table. It is impossible to tell from the data in the table whether any of the yield decline is attributable to climate change. The sections that follow, however, use models to help us better understand how continuing climate change will affect yields.

The Current Climate in Africa

This section focuses on the climate in Africa and the change that has already taken place. Here, we use the AgERA5 climate dataset (Boogaard et al. 2022), which is derived from the ECMWF ERA5 reanalysis. Figure 6.1 shows the annual precipitation and mean annual temperature circa 2000. The figure represents the predicted value of each based on a linear regression on the historical data from 1979 to 2021. In a very real sense, these are the climate means for 2000. We note the heterogeneity of climate in Africa, with much of northern Africa being extremely arid, along with parts of western Southern Africa and the eastern half of eastern Africa. We also note areas of high rainfall, mostly along certain coastlines and in mountainous regions. In terms of temperature, the Sahel is much warmer than the rest of the continent. Cooler areas exist in the highlands and along parts of the Mediterranean coast.

Figure 6.2 shows that climate change is already taking place and has shifted rainfall and temperature patterns in much of the continent. The maps are produced from regressions at each pixel in the AgERA5 dataset (Boogaard et al. 2022). White areas mean that the trend was not statistically significant at the 10 percent level. Figure 6.2 also shows that much of the central part of the continent has experienced a significant drying trend over the 43-year period in the dataset. In addition, a few areas in southern Africa and Angola in central Africa are notably wetter. Most of

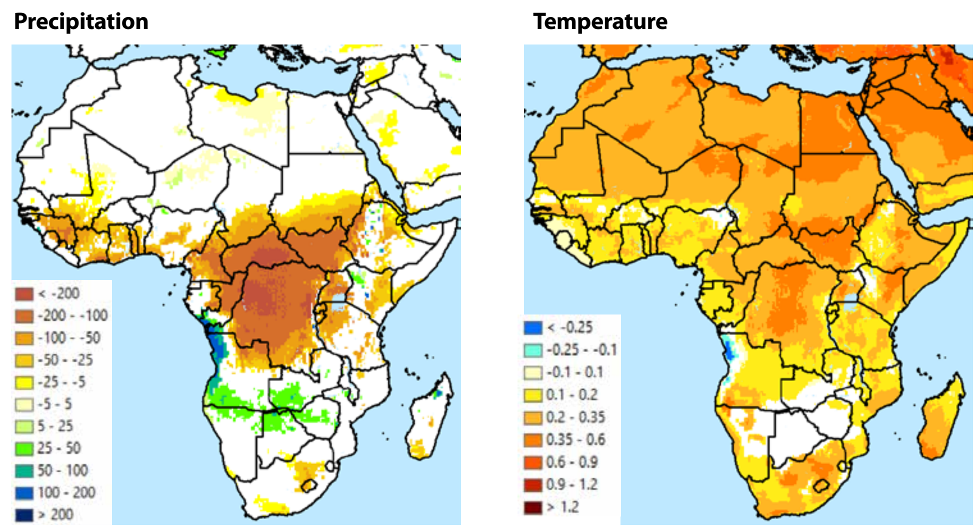
FIGURE 6.1—ANNUAL PRECIPITATION (MM) AND MEAN ANNUAL TEMPERATURE (°C), CIRCA 2000



Source: Boogaard et al. (2022). Note: Averages for 1985 to 2015.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

FIGURE 6.2—PRECIPITATION CHANGE (MM) AND TEMPERATURE CHANGE (°C) PER DECADE, 1979–2021



Source: Boogaard et al. (2022). Note: The figure shows only changes with a 90% confidence interval based on regression parameter estimates and their standard errors. To determine annual change, the legend can be divided by 10, and for the entire 43-year period, it can be multiplied by 4.3.

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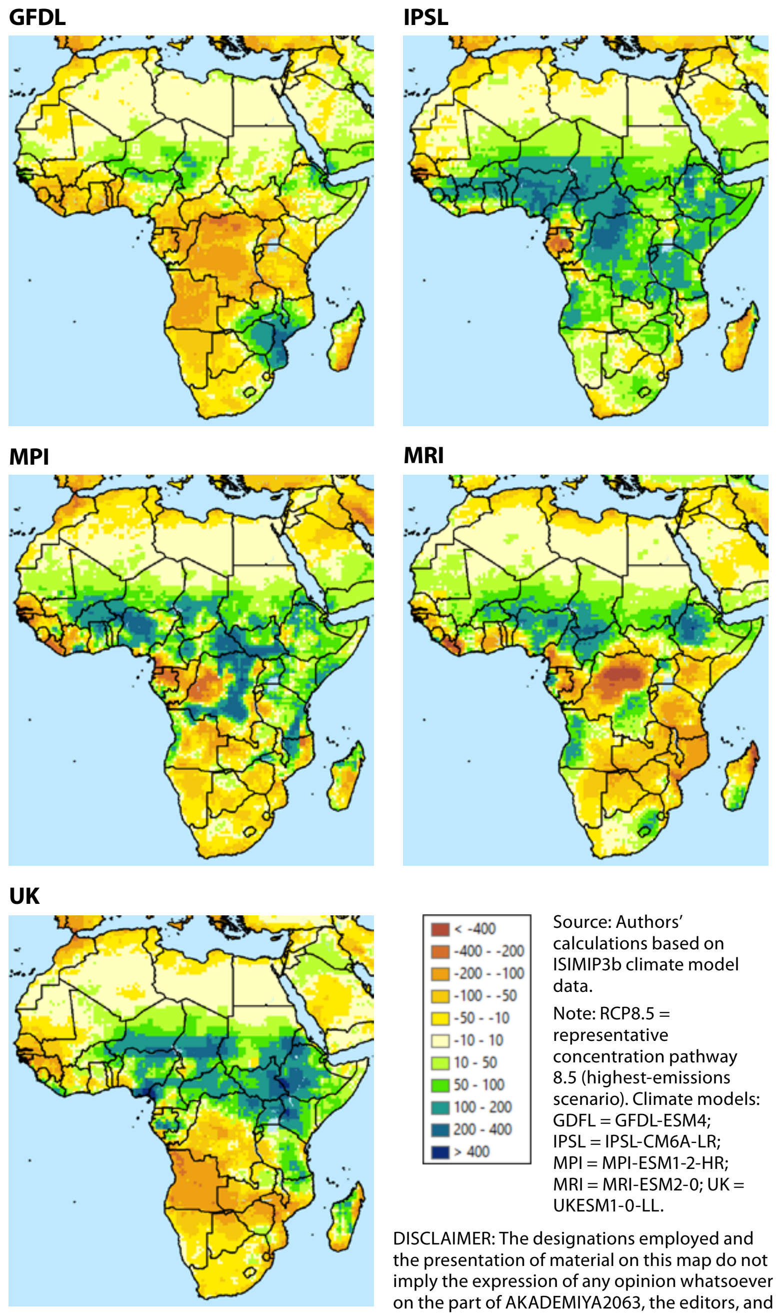
FIGURE 6.3—PROJECTED CHANGE IN ANNUAL PRECIPITATION (MM), 2020–2050, RCP8.5



Source: Authors' calculations based on ISIMIP3b climate model data.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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the continent has experienced statistically significant increases in temperature, with the highest concentrated in northern and central Africa.

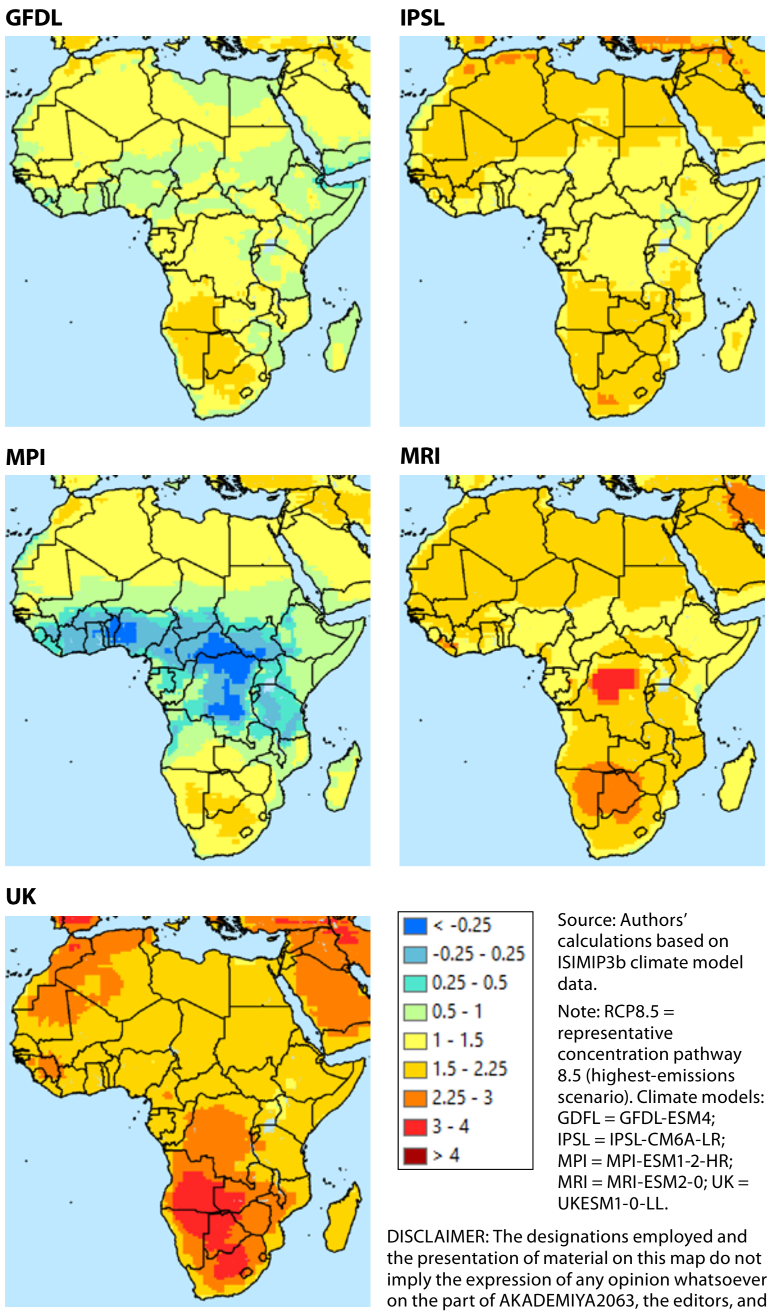
Projected Changes in Climate for Africa

Figure 6.3 shows the annual precipitation changes from 2020 to 2050 for the five climate models used throughout this chapter for the RCP8.5 scenario. As can be easily seen, the models are not in total agreement about the direction and magnitude of change in precipitation. Generally, southern Africa is projected to become drier, though this is less clear for Malawi, Mozambique, Zambia, and Zimbabwe. Much of eastern Africa, particularly Ethiopia, is projected to become wetter. In fact, in all the models, there is a band of rainfall increase that extends westward from Ethiopia to Mali or beyond. Rainfall projections for central Africa differ across models. One of the main points for the reader to understand is that there is considerable uncertainty about the direction and magnitude of change. Therefore, donors, policymakers, researchers, and farmers need to be careful not to make policies, plans, and investments that will be successful only if a particular future climate scenario becomes reality. Models that account for climate uncertainty can be used to assess alternative future scenarios and inform the decision-making process.

Furthermore, in addition to uncertainty about the direction and magnitude of average precipitation change, much has been written about increasing variability, of rainfall in particular, under climate change, and the possibility that rainfall events will become more intense, with more precipitation falling in a shorter amount of time. The climate and economic modeling results presented in this chapter do not reflect the potential for increasing variability, in part because they focus on average results for each climate model, but also because most climate models do not project large increases in variability.

Figure 6.4 shows the ranges of temperature change projected for the five climate models in this study. The IPSL projections show the least change in temperature, particularly in the middle latitudes. In fact, all the models, except possibly the UK model, project the least temperature change near the equator, though much of this zone of low temperature increase is located from the equator northward to 15 to 20 degrees north latitude. The UK climate model shows the greatest changes in temperature, with southern Africa having the greatest increase on the continent, particularly in Angola (which is classified as part of central Africa in this chapter), Botswana, Namibia, and South Africa. Since the UK model also projects a drier southern Africa, this means that the UK climate model projects the greatest negative impact on agriculture. The MRI model shows the second-greatest increase in temperature, with part of the Democratic

FIGURE 6.4—PROJECTED CHANGE IN MEAN DAILY MAXIMUM TEMPERATURE (°C), 2020–2050, RCP8.5



Source: Authors' calculations based on ISIMIP3b climate model data.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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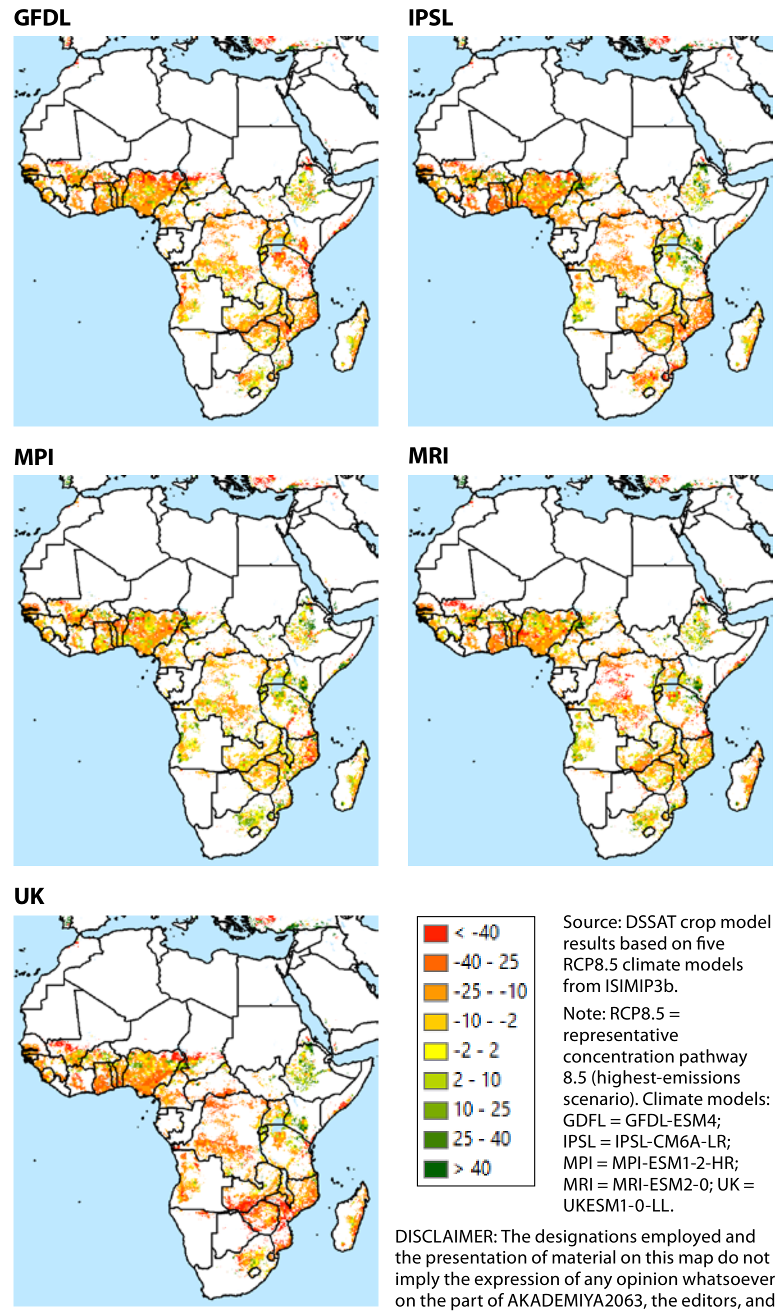
FIGURE 6.5—PERCENTAGE CHANGE IN RAINFED MAIZE YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5



Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Climate models: GDFL = GFDL-ESM4; IPSL = IPSL-CM6A-LR; MPI = MPI-ESM1-2-HR; MRI = MRI-ESM2-0; UK = UKESM1-0-LL.

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Republic of the Congo warming more than the rest of the continent.

TABLE 6.2 —PERCENTAGE CHANGE IN RAINFED YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5

Country/ region	Median	Range		Includes CO_2
		Min	Max	
Groundnuts				
World	**9.3**	6.1	15.0	20.2
Africa	**6.8**	−3.6	8.8	20.9
Eastern Africa	**12.4**	−11.0	15.8	21.0
Central Africa	**9.3**	2.7	14.3	22.4
Northern Africa	**4.1**	−23.4	37.7	22.1
Southern Africa	**5.3**	−9.4	15.0	18.8
Western Africa	**3.0**	−5.7	8.0	20.5
Maize				
World	**−12.5**	−36.2	−8.1	3.8
Africa	**−11.0**	−14.8	−5.6	−0.1
Eastern Africa	**−3.0**	−17.1	2.2	−0.2
Central Africa	**−11.3**	−18.9	−7.6	−0.2
Northern Africa	**−26.4**	−38.5	−7.8	0.0
Southern Africa	**-9.4**	−18.0	−1.4	−0.1
Western Africa	**−17.7**	−18.8	−13.0	−0.2
Potatoes				
World	**0.9**	−14.0	11.0	17.0
Africa	**−16.4**	−32.4	−3.4	12.0
Eastern Africa	**−6.0**	−19.0	1.0	11.8
Central Africa	**−29.8**	−59.2	0.3	8.3
Northern Africa	**11.0**	−17.2	31.9	29.0
Southern Africa	**−28.0**	−51.5	−6.6	13.3
Western Africa	**−57.0**	−81.4	−32.9	5.4
Rice				
World	**8.2**	3.7	14.7	15.0
Africa	**2.9**	−4.4	4.0	11.0
Eastern Africa	**−4.5**	−18.8	10.0	9.6
Central Africa	**2.0**	−7.0	3.6	11.2
Northern Africa	**29.5**	6.7	52.9	15.4
Southern Africa	**6.6**	1.3	12.5	8.8
Western Africa	**3.4**	−3.3	5.8	12.1
Sorghum				
World	**−2.4**	−5.9	−0.2	2.2
Africa	**−1.1**	−13.2	0.6	1.2
Eastern Africa	**9.3**	−7.9	11.2	0.8
Central Africa	**−0.8**	−5.8	3.8	0.8
Northern Africa	**5.7**	−23.2	8.8	1.8
Southern Africa	**2.9**	−7.4	4.6	0.9
Western Africa	**−5.2**	−11.8	−1.8	0.8
Soybeans				
World	**6.9**	−1.7	19.1	22.1
Africa	**13.0**	8.7	16.4	22.6
Eastern Africa	**21.9**	2.5	34.3	26.5
Central Africa	**12.6**	8.5	16.8	23.5
Northern Africa	**28.7**	20.8	62.6	22.1
Southern Africa	**11.0**	0.3	27.5	21.2
Western Africa	**12.2**	4.1	17.9	22.4
Wheat				
World	**21.1**	17.1	24.3	14.4
Africa	**−31.3**	−37.0	−22.0	6.9
Eastern Africa	**1.1**	-1.0	3.1	12.8
Central Africa	**−5.0**	−11.3	3.1	11.6
Northern Africa	**−42.5**	−50.9	−31.7	4.9
Southern Africa	**−4.9**	−22.6	1.6	10.7
Western Africa	**−21.2**	−34.2	48.0	8.5

Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes no adaptation measures such as changing crop mixes or cultivars in any given location. It also assumes no land expansion.

Direct Impact of Climate Change on Yields

This section presents yield computations from the DSSAT crop model for seven key crops, based on the climates of 2005 (baseline) and 2050. This analysis was performed separately for rainfed and irrigated crops. Space does not allow the presentation of maps for all the crops, but Figure 6.5 shows the location-specific changes in rainfed maize yields as a result of the climate change projected by each climate model, assuming farm management practices do not change over time. In South Africa, some of the climate models suggest that maize yields will improve, while in other models, such as the very hot UK model, they are projected to decline. However, Nigeria, for example, shows yield decreases in much of its area in every climate model. This is because the growing season in most parts of South Africa is cooler than in Nigeria; thus, additional heat in South Africa could push the temperature closer to the optimal temperature for maize, whereas the temperature in Nigeria appears to already be above the ideal for maize, so with climate change making it hotter still, yields decline.

With the equator passing through eastern Africa, one would assume that temperatures there are already higher than the optimal for growing maize. But much of the maize in eastern Africa is grown in the highlands, where the elevation keeps the temperature cooler. Hence a modest temperature increase raises yields. Increased rainfall in eastern Africa also contributes to the higher yields projected in much of the region.

Table 6.2 summarizes the findings of the crop modeling analysis for the seven rainfed crops, aggregated to the continent and the five subregions. The main findings are in the "Median" column, which represents the median value across the five climate models used. These results include CO_2 fertilization. The range across the five models is given by the "Min" and "Max" columns. To obtain a measure for climate change that excludes CO_2 fertilization, the value in the "Includes CO_2" column can be subtracted from the "Median" column.

Beginning again with rainfed maize, let us look at the tabulated results presented in Table 6.2. In Africa as a whole, climate change is projected to reduce rainfed maize yields by 11 percent at the median. But this suggests that Africa may have a very slight comparative advantage with regard to maize and climate change, since the world as a whole is projected to experience a more than

12 percent yield reduction. If the most negative climate model proves to be correct, Africa will have a major comparative advantage vis-à-vis the rest of the world, with a 15 percent yield reduction for Africa compared to a 36 percent yield reduction for the whole world. We also see that the world's yield would be reduced by an additional 4 percent without CO_2 fertilization, while almost no CO_2 fertilization effect is projected for Africa.

With sorghum, the story is similar, though the magnitude of the yield reduction due to climate change is roughly 10 percentage points less for sorghum. At the median, Africa is projected to lose 1 percent, while the world as a whole is projected to lose more than 2 percent. However, in the most negative climate model, Africa is projected to see a greater reduction than the rest of the world.

Climate change (with the CO_2 fertilization effect) is projected to have a positive impact on rice, soybean, and groundnut yields in Africa—with a CO_2 boost of 11, 23, and 21 percent, respectively. Of the three crops, only soybeans represent a comparative advantage for Africa compared to the rest of the world—though currently soybeans are cultivated only in relatively small areas in Africa. Potatoes and wheat in Africa, however, are projected to experience large yield losses due to climate change, with wheat in particular seeing a 52 percentage point difference compared to the whole world (a 31 percent loss for Africa and a 21 percent gain for the world). Northern Africa is projected to see a more than 42 percent reduction in rainfed wheat yields (the decrease is much less for irrigated yields—only 5 percent—but roughly two-thirds of wheat grown in northern Africa is rainfed). Eastern Africa is actually projected to receive a small boost in wheat yields from climate change—though still a 20 percentage point lower boost relative to the whole world.

Table 6.3 shows the impact of climate change on irrigated crops, based on projections using the DSSAT crop model. Northern Africa appears to have half of the continent's irrigated crops (measured by harvested area). Roughly a third of the harvested area in northern Africa is irrigated. Southern Africa, with 18 percent irrigated, is the only other subregion with more than 6 percent of harvested area irrigated. Apart from wheat, irrigated crops in Africa have roughly the same or better yield projections than the rest of the world. For wheat, Africa is projected to have yields that are more than 4 percent lower, while the world is projected to have yields that are 8 percent higher.

While the concept of comparative advantage arising from climate change gives some idea of how agriculture may change in Africa, the IMPACT model more fully incorporates not only climate change but also productivity changes due to investment in new crops, fertilizer, and agricultural extension, as well as changes in global demand, to indicate how African agriculture will likely evolve by 2050. Those results are presented in the following section.

TABLE 6.3—PERCENT CHANGE IN IRRIGATED YIELDS DUE TO CLIMATE CHANGE, 2005–2050, RCP8.5

Country/region	Median	Range		Includes CO_2
		Min	Max	
Groundnuts				
World	**5.6**	−6.8	10.6	17.1
Africa	**2.3**	−8.7	11.6	19.5
Northern Africa	**1.4**	−9.9	11.5	19.7
Southern Africa	**10.2**	−1.0	15.2	17.9
Maize				
World	**−18.9**	−29.8	−12.6	1.8
Africa	**−5.5**	−9.5	−1.4	0.8
Eastern Africa	**−14.7**	−24.0	−11.0	2.0
Central Africa	**−18.7**	−29.2	−13.9	2.6
Northern Africa	**−1.5**	−5.2	3.5	0.0
Southern Africa	**−9.8**	−11.7	−6.6	1.5
Western Africa	**−26.4**	−37.7	−18.2	2.5
Potatoes				
World	**8.0**	−1.0	12.3	18.2
Africa	**26.2**	21.0	27.4	33.9
Northern Africa	**28.5**	23.7	30.8	34.6
Western Africa	**<−50**	<−50	−9.9	1.5
Rice				
World	**7.8**	4.9	9.6	14.2
Africa	**5.4**	1.2	6.3	10.9
Eastern Africa	**3.1**	1.4	4.4	12.1
Central Africa	**7.0**	1.9	11.7	17.4
Northern Africa	**4.8**	−7.3	6.0	19.7
Southern Africa	**6.5**	5.7	8.7	7.9
Western Africa	**2.0**	−7.8	6.4	14.4
Sorghum				
World	**−2.7**	−5.7	3.1	0.4
Africa	**−3.0**	−5.7	−2.3	1.0
Eastern Africa	**−7.4**	−13.6	−4.4	0.3
Northern Africa	**−3.2**	−4.9	−1.7	0.9
Western Africa	**0.8**	−7.1	2.9	0.9
Wheat				
World	**8.0**	6.4	10.4	8.4
Africa	**−4.5**	−10.1	0.9	9.6
Northern Africa	**−5.4**	−10.2	0.6	9.3
Southern Africa	**0.6**	−7.4	2.6	10.1
Western Africa	**−6.9**	−33.1	5.3	12.1
Soybeans				
World	**6.5**	−13.2	10.4	16.6
Africa	**14.2**	10.0	14.9	17.3
Southern Africa	**14.2**	10.0	14.9	17.3

Source: DSSAT crop model results based on five RCP8.5 climate models from ISIMIP3b.

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). Regions were omitted if they have less than 5,000 hectares of the crop according to SPAM 2005v3.1 (You et al. 2014).

Projections for African Agriculture

IMPACT is a multimarket partial equilibrium model of global food and agriculture that was first developed in the mid-1990s (Robinson et al. 2024; Rosegrant et al. 2024). It is used to run scenarios projecting changes in supply and demand for 159 countries and 62 agricultural commodities into the future—currently up to 2050. It integrates economic, climate, water, and crop models. The IMPACT model takes into account changes in global demand (driven primarily by changes in population, income, and consumer tastes) and changes in global supply (driven by assumptions about growth in cropland and improvements in agricultural production technology), and solves for the global price of each commodity that equalizes global supply and demand. As part of this process of equalizing global quantities supplied and demanded, farmers decide whether to increase or decrease the amount of land allocated to each crop based on profitability and comparative advantage. They also make decisions about how intensively to manage each crop, which affects yields.

This section reports on IMPACT model projections that rely on the climate models previously discussed in this chapter and the crop model results presented in the preceding section. Table 6.4 summarizes key IMPACT model projections for the continent for the 10 leading crops by area harvested, under the high-emissions scenario (RCP8.5) and the middle-of-the-road economic scenario (SSP2). Table 6.5 does the same thing for the top five crops for each subregion. Similar to Tables 6.2 and 6.3, these tables report the median change along with the range across the five climate models. But it is important to understand that the median and range include projected changes in productivity levels as well as the climate and CO_2 fertilization effects. To break these down further, the "Clim" column reports the climate effect (ignoring CO_2 fertilization), and the "CO_2" column reports the CO_2 fertilization effect. So, the productivity growth effect without the climate and CO_2 effects is the "Median" minus the sum of "Clim" and "CO_2." For example, the pure productivity growth effect for maize yield is 23.4 minus –2.9 (that is, –3.4 plus 0.5), which is approximately 26.3 percent.

TABLE 6.4 —PROJECTED CHANGES IN PRODUCTION FOR THE TOP 10 CROPS FOR AFRICA, 2020–2050, RCP8.5

Crop	Cultivated area, 2020 (000s hectares)	Percentage change in yield, 2020–2050					Percentage change in harvested area, 2020–2050					Percentage change in production, 2020–2050				
			Range		Includes			Range		Includes			Range		Includes	
		Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2
Maize	39,721	23.4	21.9	26.6	–3.4	0.5	18.6	15.5	22.0	5.8	2.1	49.1	40.7	52.4	4.7	2.1
Sorghum	28,009	45.6	44.3	46.6	–0.5	0.0	44.3	44.0	45.6	0.6	1.3	110.8	108.1	111.9	0.7	1.1
Cassava	21,272	22.8	22.0	25.5	0.4	–0.5	24.1	23.1	24.7	–0.7	1.1	52.5	51.1	54.5	–0.3	0.7
Millet	20,429	60.6	53.1	68.5	5.3	0.0	33.3	31.4	33.8	–2.3	0.5	113.9	101.1	121.6	2.9	0.5
Rice	17,124	40.6	38.0	46.4	–6.9	5.9	8.2	6.9	10.8	–0.8	–5.0	52.2	47.6	62.3	–7.5	0.7
Groundnuts	17,039	17.5	13.5	21.4	–9.1	8.7	33.8	31.6	39.4	5.5	–7.1	59.0	56.9	60.1	–3.2	2.3
Cowpeas	14,238	69.2	60.9	71.1	1.0	2.2	33.4	33.1	36.8	–0.7	–0.7	125.7	120.3	127.7	0.3	1.4
Wheat	9,912	37.7	36.3	41.8	–11.0	5.2	1.2	0.1	3.4	–5.7	0.2	39.6	36.5	46.5	–16.0	5.2
Beans	9,736	44.5	39.3	46.3	1.5	4.3	40.7	40.3	43.7	1.2	–3.3	104.2	95.4	109.7	3.1	1.0
Vegetables	9,474	43.8	39.9	50.6	–10.1	5.6	31.4	29.4	32.7	–3.7	–1.2	87.7	81.3	99.2	–13.9	4.1

Source: Rosegrant et al. (2024).

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes CO_2 fertilization. Median results are from five global climate models. "Clim" compares the counterfactual results if the climate did not change beyond 2020 to scenarios with climate change but no CO_2 fertilization (the climate-only effect). "CO_2" is the change when CO_2 fertilization is taken into account.

As mentioned in the opening to this section of the chapter, the reader should keep in mind that every number in every column accounts for substitution effects from the changes in global supply and demand that determine global prices. So, while the CO_2 effect for groundnuts in Africa in Table 6.2 is 21 percent, in Table 6.4 it is under 9 percent. This reflects the expectation that worldwide, with CO_2 fertilization, global production will be boosted, which would drive prices down and disincentivize farmers from taking additional steps to increase productivity.

Table 6.4 also differs from Tables 6.2 and 6.3 in that it includes projected changes to harvest area and production. Table 6.2 shows that Africa would have a strong comparative disadvantage in growing wheat in the future due to climate change. As a result, we see in Table 6.4 that of the 10 crops presented, area growth is by far the smallest for wheat, with an increase of just 1 percent. Even with a very respectable 38 percent projected growth in yield between 2020 and 2050, wheat is also projected to have the smallest increase in total production among the top 10 crops, with an increase of slightly less than 40 percent.

This is not very much less than the projected production increase for maize, at 49 percent. But the change in maize production was more balanced, with a 19 percent increase in harvested area and a 23 percent increase in yield. Cereals that might be considered maize substitutes—sorghum and millet—are projected to have a total production increase more than twice as fast as maize, with sorghum production increasing by almost 111 percent and millet production increasing by 114 percent.

Millet yields will increase faster than sorghum yields between 2020 and 2050, with a growth rate of 61 percent (the second-highest rate of growth among the top 10 crops) compared to 46 percent. At the same time, however, sorghum area will grow faster than millet area, at a rate of 44 percent (the highest among the top 10 crops) compared to 33 percent.

The only other cereal in the top 10 crops for Africa is rice. Its area growth is projected to be the second slowest among the top 10 crops, at 8 percent, ahead of only wheat. However, rice yields are projected to grow by 41 percent, leading to a 52 percent total production growth.

The crop projected to have the greatest increase in production is cowpeas, with a 126 percent increase driven by a 69 percent growth in yields—the highest among the top 10 crops—and a 33 percent increase in harvested area. The other legume in the table—beans—is also projected to see significant growth in production, at 104 percent, driven by yield growth of nearly 45 percent and area growth of 41 percent (the second-highest area growth, behind only sorghum).

Table 6.5 shows subregional production projections. In eastern Africa, we see sorghum production projected to grow by 168 percent between 2020 and 2050, driven by a 72 percent increase in harvested area and a 56 percent boost in yields. Similarly, central Africa is projected to have a large increase in the production of sorghum, with 132 percent growth, due to a 59 percent increase in area and a 46 percent increase in yields. Sorghum will also see the most rapid expansion of area among the top five crops in northern Africa and western Africa.

In southern Africa, production of rice is projected to increase by 139 percent, driven by a 93 percent increase in yields (though almost none of this is climate related). Bean production in southern Africa is similarly projected to grow by 135 percent, with the growth split between a 56 percent yield increase and a 51 percent area increase. In western Africa, cowpea production is projected to expand by 121 percent, led by a 68 percent yield increase.

Finally, it is important to note the 29 percent decline in barley production in northern Africa, reflecting a 14 percent decline in yield and an 18 percent decline in harvested area.

Focusing on the “Clim” and “CO_2” columns, we see that northern Africa experiences the greatest yield shocks from climate change, which in some cases translates into significant reductions in harvested area as well, resulting in fairly large production shocks for barley and wheat in northern Africa. Teff is projected to have a 10 percent production shock in eastern Africa, and rice has a 9 percent production shock in western Africa (though only 6 percent with the CO_2 fertilization effect).

Generally, the impact of climate change on crops in an average year and in the aggregate seems relatively modest in Africa, according to the IMPACT model results presented in Table 6.5. Some yield gains are projected from climate change and, of course, also some declines. What is not accounted for in the model are the national and subnational shocks, which are averaged out at the continent and subregion levels and therefore will be more extreme. Above, Figure 6.5 is cited as an example of the spatially differentiated impact of climate change on yields—how it creates “hot spots,” or areas of high average losses, while also creating spots of opportunity, where yields increase as a result of climate change. Hot spots are part of the reason that climate change can be

TABLE 6.5 —PROJECTED CHANGES IN PRODUCTION FOR THE TOP 5 CROPS FOR EACH AFRICAN SUBREGION, 2020–2050, RCP8.5

Crop	Cultivated area, 2020 (000s hectares)	Percentage change in yield, 2020–2050					Percentage change in harvested area, 2020–2050					Percentage change in production, 2020–2050				
			Range		Includes			Range		Includes			Range		Includes	
		Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2	Median	Min	Max	Clim	CO_2
Eastern Africa																
Maize	10,053	35.5	30.1	39.4	0.2	0.6	15.1	13.3	18.9	4.4	2.0	56.0	47.5	65.9	4.6	2.6
Beans	5,006	43.4	34.6	45.7	2.8	6.6	33.1	31.6	37.0	1.4	–2.6	91.4	77.8	99.4	4.4	4.0
Sorghum	3,759	56.1	55.5	57.2	1.8	–0.9	71.8	70.8	72.5	1.7	1.2	168.2	165.9	170.0	3.4	0.4
Teff, etc.	3,282	50.9	47.7	57.7	–4.6	3.0	13.2	12.6	14.3	–6.1	–1.8	70.2	66.4	79.5	–10.4	0.7
Cassava	3,021	51.3	47.2	53.2	–0.1	–0.4	23.0	21.6	23.6	–0.5	0.8	86.1	82.0	87.8	–0.6	0.4
Central Africa																
Maize	7,011	31.6	19.8	33.4	–7.6	1.3	24.0	21.5	25.5	2.7	1.1	61.3	49.8	65.5	–6.1	2.2
Cassava	6,660	30.3	26.3	32.6	0.2	–0.2	24.9	24.0	25.5	–0.4	0.7	62.5	57.8	65.9	–0.5	0.6
Groundnuts	2,315	23.8	21.1	24.9	–1.2	4.4	43.5	40.8	50.4	5.3	–6.3	76.7	73.7	86.1	3.4	–1.8
Sorghum	2,063	46.0	43.5	50.4	–3.6	0.3	58.8	58.2	60.2	0.8	0.8	132.1	127.6	139.4	–2.8	1.2
Rice	2,003	34.6	24.2	38.4	–6.7	7.7	13.7	9.3	16.3	–0.1	–5.9	53.1	35.6	60.4	–6.8	1.8
Northern Africa																
Sorghum	7,312	26.5	23.9	28.3	–1.0	0.4	39.7	38.8	41.4	0.8	1.5	76.5	73.0	81.4	–0.5	2.0
Wheat	7,244	25.1	22.4	30.4	–13.5	4.3	–9.5	–10.2	–7.2	–5.8	–0.1	14.0	9.7	21.0	–18.7	4.7
Other oilseeds	3,919	21.1	17.9	25.6	–7.7	2.8	27.7	25.3	29.6	6.8	–5.1	54.9	52.9	57.7	–0.8	–2.3
Rapeseed	3,516	4.0	3.4	5.6	–0.6	–3.0	5.9	4.9	6.4	–1.3	–4.0	9.9	8.4	12.4	–2.0	–6.9
Vegetables	3,441	–13.7	–15.8	–11.0	–11.3	1.6	–17.8	–18.0	–16.7	–6.2	–2.1	–29.1	–30.8	–26.8	–16.8	–0.5
Southern Africa																
Maize	7,949	18.8	17.2	29.9	–7.6	0.4	16.5	13.8	19.4	4.5	2.6	40.0	35.1	54.2	–1.9	2.4
Rice	1,716	92.9	91.0	96.7	0.5	1.2	24.4	23.6	26.5	0.3	–4.9	139.2	138.0	148.9	0.6	–3.9
Cassava	1,524	38.6	35.8	44.2	–0.3	–1.0	18.2	17.0	19.4	–1.5	1.4	63.3	59.3	70.4	–2.0	0.3
Groundnuts	1,479	22.1	21.5	22.6	–3.4	5.9	32.2	27.5	37.3	7.0	–8.7	60.7	56.4	67.6	2.7	–2.4
Beans	1,438	55.9	45.4	63.6	0.2	–0.9	51.3	47.7	55.8	–1.2	–4.1	134.7	114.7	155.1	–1.0	–5.4
Western Africa																
Sorghum	14,254	39.4	35.9	40.4	–0.7	0.3	37.0	36.4	38.6	0.2	1.3	90.6	85.3	93.1	–0.6	1.5
Millet	14,016	51.2	49.0	59.7	3.9	0.2	27.9	27.3	29.4	–2.6	0.4	94.5	90.7	103.2	1.7	0.7
Maize	13,499	12.5	8.4	16.8	–3.8	0.5	18.1	13.5	22.4	8.9	2.6	32.8	28.0	37.9	5.6	2.2
Cowpeas	12,732	68.3	58.6	70.1	1.7	2.0	31.5	31.2	34.0	–0.6	–0.7	121.3	112.4	123.2	1.0	1.3
Rice	11,567	39.6	36.1	44.3	–7.7	6.8	6.8	5.3	8.7	–1.1	–4.5	49.1	43.2	56.3	–9.0	2.6

Source: Rosegrant et al. (2024).

Note: RCP8.5 = representative concentration pathway 8.5 (highest-emissions scenario). The model assumes CO_2 fertilization. Median results are from five global climate models. “Clim” compares the counterfactual results if climate did not change beyond 2020 to scenarios with climate change but no CO_2 fertilization (the climate-only effect). “CO_2” is the change when CO_2 fertilization is taken into account. “Other oilseeds” include sesame and safflower. Oilseeds that are already accounted for are groundnuts, soybeans, sunflowers, rapeseed, and oil palm.

very harmful to farmers, agriculture, food security, and livelihoods, even when averages at the national level do not indicate reasons for alarm.

Low-yield Events Arising from Extreme Climate Events

What is also not accounted for in this analysis are the yield shocks associated with droughts, floods, and heat waves, along with other climate impacts that occur during extremely adverse years. Thomas and colleagues (2022) examine the incidence of low-yield events for maize in 10 countries in southern Africa. One of their findings is that under the highest-emissions scenario—similar to the RCP8.5 scenario used in this chapter—the frequency of what is currently a 1-in-20-year low-yield event will occur every 3.5 years by the 2060s. This result is driven by the change in the mean temperature and precipitation and by uncertainty about the future. If variability of precipitation were to increase, as some climate models suggest, then low-yield events would occur even more frequently.

Thomas and colleagues (2022) were also able to compute changes in the frequency of low-yield events at the pixel level to produce a map similar to the one in Figure 6.5 in this chapter. Such a map can help policymakers identify high-risk areas and guide them in creating strategies and investments to lower the risk to farmers in those locations.

Future Areas of Research

In addition to expanding the study of the consequences of increased precipitation variability, subject areas that deserve additional research include the impact of heat on agricultural labor productivity and the impact of heat and drought stress on the productivity, morbidity, and mortality of livestock and fisheries. One of the greatest challenges in modeling these issues is determining how much adaptation can take place. For example, heat stress on laborers could lead to substituting labor with more mechanical devices such as tractors. Nelson and colleagues (2024) endeavor to account for forms of adaptation to heat stress on labor and livestock through, for example, measures such as providing shade or fans for cooling.

Concluding Remarks

Table 6.2 showed that with climate change, some crops—including maize, sorghum, and soybeans—will see either a greater production boost or a lower loss in Africa than in the rest of the world. Groundnuts and rice will do modestly worse than in the rest of the world, but wheat and potatoes will suffer large losses that are much greater than those seen in the world as a whole.

The impact of climate change, however, is not uniform throughout Africa. Northern Africa appears likely to fare worse than the rest of the continent because of the importance of wheat and barley in its current agriculture system; these crops are projected to experience large declines due to climate change, while for the rest of the world, yields of wheat and barley will rise due to climate change. Eastern Africa, despite being on the equator, will possibly fare best among all the subregions under climate change, in large part due to the higher elevation at which most of its cropping takes place, which keeps temperatures cool.

Climate change is not uniform within subregions or within countries either. We saw in Figure 6.5 how the same country can experience yield improvements from climate change in some locations along with large declines in other locations.

In addition to spatial heterogeneity creating hot spots with climate change, temporal heterogeneity—interannual variability of the weather—deserves more research because the shocks, or bad years, are the ones that cause the greatest threat to food security. More consideration should be given not only to reducing risk for farmers but also to smoothing prices and food availability for consumers. Establishing strategic reserves is one way to do this, but it is not the only way.

One large area of uncertainty is related to the issue of CO_2 fertilization (US Department of Energy 2020). Experts make passionate arguments for and against including the effect in modeling (Allen et al. 2020; Li et al. 2017; Toreti et al. 2020; Zhu et al. 2023). For some crops, including the effect can result in projected yields that are 20 to 25 percentage points higher over a 30-year time span. The decision to include or exclude the effect creates much uncertainty in the model. However, the CO_2 fertilization effect is significantly reduced in the context of the global economic model in which substitution takes place as prices rise or fall based on production.

As we saw in Figures 6.3 and 6.4, there are large differences among climate models, including a wide range in the projected temperature change (from little warming to much hotter) and precipitation (some predict a drier future, and some predict a wetter future). Policymakers cannot make policies based on just one selected climate model, because they may be very wrong. The best policies and investments are those that give farmers multiple options for adaptation, reduce risk, or increase productivity over a wide range of climate outcomes. Models such as DSSAT and IMPACT, which are used in this study, can be used to run scenarios to guide decisions by policymakers.

As a whole, climate-related risk to agriculture in Africa is modest in an average year. But climate change will increase production risk, and some areas and some crops are at much greater risk. Strategies should focus on reducing risk, especially in areas where the risk is known to be high. Plans should incorporate important components such as agricultural research to develop new varieties and techniques; information services to help farmers adapt more quickly; and risk-reducing approaches such as irrigation, mechanization, and agroforestry.

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The author accepts responsibility for any errors that appear in this paper.

CHAPTER 7

Adaptation Actions to Climate Change in African Agriculture: Effectiveness and Challenges

Getaw Tadesse and Ndeye Yacine Barry

Introduction

Climate change poses a significant burden to African development and economic growth, impacting households at both national and regional levels. While accounting for only 3–4 percent of global emissions, Africa is most vulnerable to climate change due to low levels of socioeconomic growth (Kikstra et al. 2022). Africa's vulnerability to climate change is exacerbated by its reliance on rain-fed agriculture, environmental degradation, inadequate infrastructure, widespread poverty, and increased frequency and intensity of climate-related disasters. These factors make Africa highly susceptible to climate-related disruptions such as droughts and floods and can amplify the impact of climate-related disasters on communities, economies, and ecosystems (UNECA 2013; WMO 2020). Effective adaptation strategies and risk financing mechanisms are crucial for building regional adaptive capacity and resilience.

Many African governments have recognized the urgent need for climate action and responses (Babatunde 2019; Damptey and Zakieldeen 2020), and many of them have developed national adaptation plans (NAPs) to combat the adverse effects of climate change. Adaptation actions are also proposed in almost all plans for nationally determined contributions (NDCs), with a particular emphasis on meeting socioeconomic priorities such as food security, income and enterprise opportunities for youth, and economic expansion. Climate change disproportionately affects the world's poorest people, particularly in developing countries, due to their limited resources and infrastructure to cope with extreme weather events and disasters (Signé and Mbaye 2022).

At the continental level, several strategies and programs have been developed to address the increasing frequency and intensity of climate hazards. These include the African Green Stimulus Programme (2022), the African Union (AU) Climate Change and Resilient Development Strategy and Action Plan (2022–2032), the Comprehensive Africa Agriculture Development Program (CAADP), and the AU's Agenda 2063: The Africa We Want. These policies emphasize the need for systematic integration of climate change responses and adaptation actions into planning and agricultural policies (Al-Zu'bi et al. 2022).

However, the implementation, adoption, and impacts of these adaptation actions have not yet reached a significant level. This is due to several factors, including the limited finance being allocated to adaptation actions compared to mitigation actions; weak institutional and human capacity to coordinate and implement proposed actions effectively; and lack of timely, relevant, and affordable climate information services that can guide not only adaptation actions but also behavioral changes (ACBF 2023). In fact, climate services can influence behavior by providing relevant information, identifying impactful actions, designing effective programs, tracking progress, and engaging communities in the process. By delivering localized data on climate risks, analyzing emissions data, and involving stakeholders in decision-making, climate services can help individuals and communities understand and address the impacts of climate change (Kelleher and Mirpuri 2023; USAID 2019). Africa urgently requires more climate finance to bridge a substantial gap. In 2020, both domestic and international climate finance flows in Africa amounted to only US$30 billion, which is far below the $250 billion needed annually from 2020 to 2030 to meet the continent's climate goals, representing just 12 percent of the required amount (Guzmán et al. 2022).[1] The majority (91 percent) of this finance came from international sources such as multilateral development institutions, bilateral partners, and international governments, while only 9 percent came from domestic sources within Africa.

This chapter aims to review and examine African climate adaptation policies and actions in terms of the typologies of actions, their state of implementation, and their effectiveness. It also examines key priority challenges facing African countries in the design and implementation of their adaptation plans, aiming to shed light on priority areas for policy actions and implications for the post-Malabo African agriculture development agenda. The chapter aims to summarize the conceptual and empirical discourses surrounding adaptation actions, with a special focus on building resilient and adaptive agriculture in Africa.

The chapter is organized as follows. The next section provides an overview of the conceptual framework that explains the differences and linkages between adaptation, resilience, and vulnerability. This is followed by a review of the African adaptation policies and plans that have led to the development of a typology of adaptation pathways to help policymakers and practitioners prioritize their options. The fourth section examines the adoption and effectiveness of

1 In this chapter, all dollars are US dollars.

selected agricultural adaptation options and reviews the state of agricultural households' resilience to climate change in Africa. The fifth section highlights key priority challenges that deserve urgent policy attention to combat the adverse effects of climate change. The final section presents concluding remarks and recommendations for the post-Malabo adaptation agenda.

Conceptual Framework

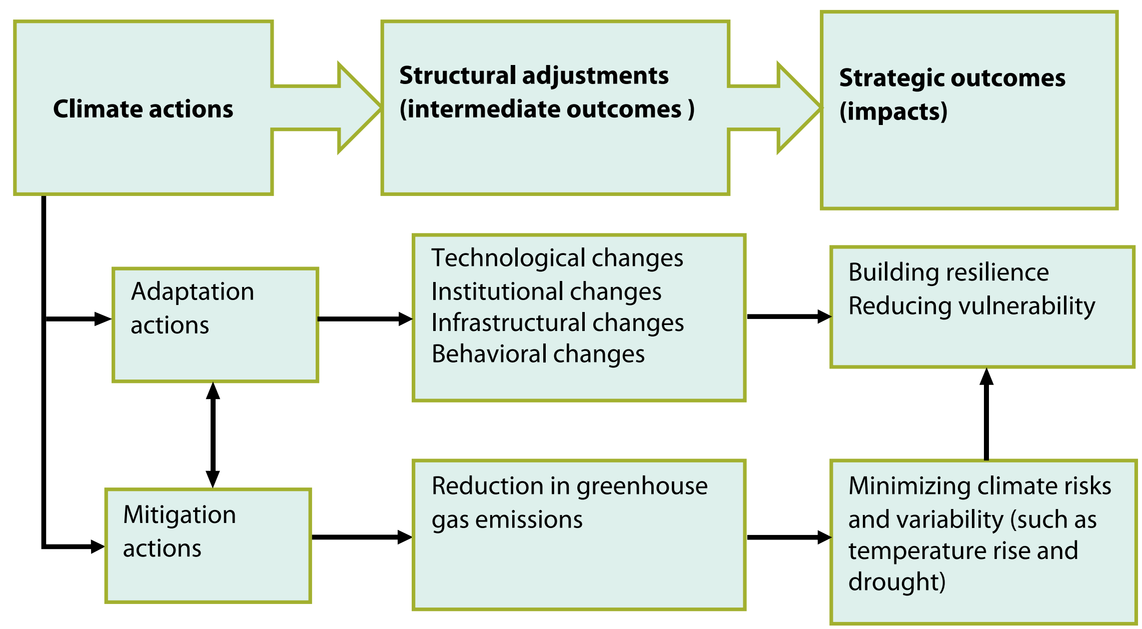
Many policy discussions and strategic documents repeatedly and interchangeably refer to adaptation, resilience, and vulnerability. Though these terms commonly refer to responses, actions, outcomes, and damages associated with a shock, they are conceptually and metrologically different, and it is important to clearly understand such differences to avoid confusion among development practitioners and actors and to guide practical analyses and actions. Therefore, in this section, we define the terms separately before going on to discuss their functional relationships.

Adaptation refers to a process that changes the natural or human system or capacity to a state that is better able to survive in a new environment (Leggett 2021). Climate actions involve adjusting policies, practices, and systems to reduce vulnerability and build resilience to climate change impacts, including sustainable land management, water conservation, and early warning systems, with the ultimate objective of minimizing the negative impacts of climate change on societies, economies, and the environment (Zolnikov 2019). One concise definition comes from the Intergovernmental Panel on Climate Change (IPCC), which states: "Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts" (IPCC 2014, 151). The ultimate aim of adaptation is to foster resilience, minimize vulnerability, and reduce the impacts of climate hazards.

Based on these definitions, adaptation involves at least three issues: (1) adaptation actions, (2) structural changes or adjustments, and (3) adaptation outcomes such as reducing vulnerability and building resilience. This means that adaptation is a process of adjustment that encompasses not only adaptation actions but also structural changes and outcomes. Figure 7.1 illustrates actions, structural changes (adjustment), and outcome indicators for adaptation as well as mitigation. The mitigation example is presented to help readers understand the counterparts. It also helps to show that adaptation and mitigations are not separable in agriculture, as shown by the double arrows between actions and strategic outcomes. Adaptation and mitigation are distinctly different only at the intermediate outcome level.

At the outcome level, adaptation aims to bring about structural changes that can suit the new circumstances and environment, while mitigation aims to reduce greenhouse gas emissions. At the impact level (sometimes called *strategic*

FIGURE 7.1—THE IMPACT PATHWAY OF ADAPTATION AND MITIGATION ACTIONS



Source: Authors' construction.

outcomes), adaptation aims to reduce vulnerability or build resilience while mitigation aims to reduce climate risks and variability. However, the impacts of both are conceptually and fundamentally interrelated. The same is true at the action level, where some actions help to achieve both mitigation and adaptation objectives.

Resilience refers to the ability of a system (ecology, economy, household, or community) to anticipate and cope with shock and bounce back from challenges, setbacks, or adversity. It involves the capacity for anticipating and coping with shocks as well as maintaining or regaining ecological, economic, social, and mental well-being in the face of climate shocks. According to Miller and colleagues (2010), resilience has been used in two ways: "one focusing on recovery and return time following a disturbance, the other focusing on how much a system can be disturbed and persist without changing function" (272). While adaptation is a process focused on adjusting to change, resilience emphasizes recovering from and overcoming hardships. This means that the purpose of adjustment to emerging new circumstances (adaptation) is to maintain the well-being caused by a shock, which is resilience.

Within the context of climate change, the IPCC defines *vulnerability* as "the extent to which a natural or social system is likely to be damaged by the impacts of climate change, and is a function of exposure, sensitivity, and adaptive capacity" (IPCC 2014, 151). Therefore, vulnerability refers to the susceptibility of a system (household, community, economy) to a shock and depends on exposure, sensitivity, and adaptive capacity.

Resilience and vulnerability are conceptually closely related and seem to be opposites of each other. However, they are metrologically and epistemologically different. While resilience measures the degree of coping and recovery (bouncing back) of a system after a shock to its original state, vulnerability measures the degree of damage caused by the shock to a system. Epistemologically, the two concepts emerge from different scientific origins. Resilience originates from ecological theory, whereas vulnerability originates from social theory (Miller et al. 2010). Nowadays, both concepts are equally applicable to social and natural systems. In terms of measurement, vulnerability depends not only on adaptive capacity but also on the impact of the shock measured by exposure and sensitivity (IPCC 2014, 151), while the measurement of resilience depends mainly on adaptive capacity as well as other public interventions at the community level (FAO 2015). The measurement of resilience should also be linked with the stability of development outcomes such as food security, household income, consumption expenditure, and the like. Weighting the adaptive capacity and other indicators based on their contribution to the development outcome usually helps to link observed indicators with development outcomes (FAO 2015).

Empirically, three analytical issues are critically important to better understand the process of adaptation and be able to guide policy actions:

1. How to measure and quantify adaptation to climate change to monitor and track performance in implementing adaptation actions
2. How to prioritize and strategize adaptation actions (this requires an understanding of the typology and characteristics of the adaptation actions)
3. Whether adaptation actions are effective in bringing impacts (this is about the empirical linkage between adaptation action and impacts, such as building resilience and reduction of vulnerability)

The latter two will be covered in subsequent sections. But when it comes to measurement, just like mitigation, adaptation is usually measured using the intermediate outcomes, such as the adoption of climate-smart agriculture (CSA) practices, for example. However, while mitigation is measured using a single indicator of reduction in greenhouse gas emissions, adaptation cannot be easily measured by a single indicator. In fact, this single indicator measurement has several weaknesses. First, it does not capture all aspects of structural adjustments. Second, since the practices are very much context-specific, it is very difficult to make comparisons across sectors and countries using one indicator; a practice that is relevant in one context may not be relevant in another context. So far, there is no standardized and comprehensive measurement for adaptation. Scholars measure adaptation using single indicators that only approximate certain dimensions of adaptation. A comprehensive and composite measurement of adaptation should include all four structural adjustments (intermediate outcomes) of adaptation (Figure 7.1). The ideal composite measurement of adaptation should also consider the relationships between these structural adjustments. One can develop a composite adaptation indicator using carefully selected indicators from each area of structural adjustment.

Review of Climate Adaptation Policies and Actions

Review of Adaptation Policies and Plans

Almost all African countries (except Libya) have developed and submitted their NDCs to the United Nations Framework Convention on Climate Change. All NDCs include two major sections on mitigation and adaptation, articulating the country's ambitions and actions. In addition to the adaptation actions set out in the NDCs, 17 African countries have also developed and adopted separate NAPs. Other countries have also developed their own national climate change and green growth strategies to foster and integrate adaptation actions in their national economic development plans. All these plans play a pivotal role in addressing the unique challenges posed by climate change on the continent. The plans serve as strategic frameworks that outline specific measures and interventions to enhance resilience and adapt to the adverse effects of climate change across various sectors. Given Africa's vulnerability to climate variability and extreme weather events, NAPs serve as essential tools for guiding policy, mobilizing resources, and coordinating adaptation efforts at national and subnational levels.

African countries face diverse climate change impacts, including droughts, floods, heat waves, and rising sea levels. These impacts threaten food security, water resources, human health, and ecosystems. NAPs are tailored to address these specific challenges by identifying priority areas for intervention, setting adaptation goals and targets, and outlining strategies for implementation. The plans often incorporate a mix of measures, such as CSA, sustainable water management, ecosystem-based adaptation, disaster risk reduction, and climate-resilient infrastructure development, all designed to build adaptive capacity and reduce vulnerability to climate-related risks. Furthermore, NAPs for African countries emphasize the importance of mainstreaming climate change adaptation into national development planning processes to ensure coherence and integration across sectors. By integrating adaptation considerations into policies, plans, and programs, countries can enhance synergies, maximize co-benefits, and minimize trade-offs between climate resilience and socioeconomic development objectives. Additionally, NAPs promote stakeholder engagement, capacity building, and knowledge sharing to foster ownership, participation, and collaboration among government agencies, civil society organizations, the private sector, academia, and local communities as part of the advancement of adaptation efforts. Overall, NAPs are instrumental in guiding Africa's response to climate change and building a sustainable and resilient future for its people and ecosystems.

At the continental level, in February 2022 the AU launched its Climate Change and Resilience Development Strategy and Action Plan following its adoption by the AU Assembly. The AU Climate Strategy is a key instrument for supporting regional collaboration on climate change and more effective international partnerships, joint actions, and the expression of collective needs and priorities. It is expected to unlock Africa's potential in building climate-resilient communities and economies, which are an integral component of the continental vision (the Agenda 2063) for "an integrated, prosperous and peaceful Africa, driven by its citizens, representing a dynamic force in the international arena" (AU 2023a). The Climate Strategy runs from 2022 to 2030 and envisions "a sustainable, prosperous, equitable and climate-resilient Africa" with a goal of "enhanced cooperation in addressing climate change issues that improves livelihoods and well-being, promotes adaptation capacity, and achieves low-emission, sustainable economic growth." Its overall objective is "building the resilience of African communities, ecosystems, and economies, and supporting regional adaptation" (AU 2023b, 121). The AU intends to reduce emissions, build resilience, and enhance green growth with nine prioritized sectoral climate actions. Despite an unclear implementation strategy and the challenges of alignment with global and national initiatives, this is an important step forward to try to address the challenges of climate change collaboratively and cooperatively at regional and continental levels. The Climate Strategy will help to mobilize joint voices, resources, and actions as well as to create mutual accountability and learning.

Although the NAPs are crucial and include significant commitments, their implementation and coordination are currently off track. This is partly because the NAPs have not yet been fully integrated into the national development plans and embraced by all stakeholders including government agencies and the private sector. Though most governments in Africa are aware of the threat posed by climate change, many still think that climate actions compete with development goals and programs.

The African Climate Change Policy Performance Index (ACCPPI) assesses the climate change policy performance of countries and regions in Africa. The index evaluates four key scores: greenhouse gas emissions (30 percent), renewable energy (25 percent), climate policy (25 percent), and corruption perception (20 percent) (Epule et al. 2021). The initial results show that Angola, Cabo Verde, Ghana, Morocco, Senegal, Tanzania, and Zambia are the best performers at the country level, while North Africa and Southern Africa are the best performers at the regional level.

The ACCPPI aims to move the climate change policy performance debate in Africa from emotional and rhetorical evaluations to more data- and evidence-based actions that facilitate policy tracking and accounting. The index will be updated every five years to incorporate new data and track developments, influencing climate change policy across Africa. It is important to highlight the excellent performance of Morocco and South Africa. Morocco is recognized as a top performer in climate change policy in Africa, with notable initiatives in place to address climate change and promote sustainable development, including the National Climate Plan 2030, the Exemplary Administration Pact, the Strategic Committee on Sustainable Development, the National Strategy for Sustainable Development 2030, the NDC and the National Climate Policy and Framework Law No. 99–12. The Mohammed VI Foundation for Environmental Protection has also launched initiatives such as the Air Climate program, which focuses on carbon compensation projects, renewable energy installations, and sustainable transportation projects. Despite not appearing among the top performing countries on the ACCPPI, South Africa is also known for its strong climate policies. The country is investing in renewable energy despite its high greenhouse gas emissions, implementing various policies and strategies such as its Biofuels Regulatory Framework, Green Fund, Low Emissions Development Strategy 2050, Integrated Resource Plan, carbon tax, Green Transport Strategy, and Climate Change Bill to improve its overall climate policy performance (Epule et al. 2021).

Regionally, North Africa and Southern Africa are leading in renewable energy and climate policies due to better governance and investments. West Africa and East Africa have moderate performance but struggle with corruption and poor climate policy environments. Central Africa has the lowest scores due to poor governance and corruption. High levels of corruption hinder the effective implementation of climate policies in many African countries. Economic disparities impact climate policy performance, with wealthier regions performing better. A comprehensive approach is needed to address climate change, including reducing greenhouse gas emissions, investing in renewable energy, and reducing corruption. The ACCPPI helps evaluate and compare climate policy performance in African countries and regions.

In contrast to the ACCPPI, the *Africa Climate Action Performance Report* evaluates Africa's climate policy through the lens of "common but differentiated responsibilities," focusing on the differences in development levels of countries (D'Souza, Jaspal, and Sengupta 2022). The report highlights that some African nations, such as Seychelles and South Africa, have high per capita carbon dioxide emissions and energy use, while others, such as the Central African Republic, Chad, and the Democratic Republic of Congo, have lower emissions levels due to their lower levels of human development.

Generally, all the assessments and evaluations indicate that countries in Africa have progressed well in terms of developing policies and strategies, but their implementation performances have remained very poor.

Typology of Adaptation Actions

A systematic assessment of observed climate adaptation responses in scientific literature covering 827 adaptation actions in 553 studies between 2013 and 2021 by Williams and others (2021) identified 24 categories of adaptation responses in Africa. Most studies were on adaptation actions in the food sector. The five adaptation response categories with the highest number of reported actions were sustainable water management (food sector), resilient infrastructure and technologies (health sector), agricultural intensification (food sector), human migration (including but not limited to poverty and livelihoods), and crop management (food sector). Urban areas reported the fewest actions. Notably, 53 percent of these actions were recorded in just six countries: Ghana, Ethiopia, Kenya, Tanzania, Nigeria, and South Africa. This indicates that these countries are prioritizing climate adaptation efforts and have made significant progress in implementing adaptation strategies.

Alongside the adaptation responses reported in these different studies, countries have also proposed numerous adaptation actions in their NDCs and NAPs. Though the proposed and reported actions all aim to build resilience and adaptation to climate shocks, there are differences in their feasibility, the required public intervention actions, and the sustainability outcomes. To help identify the priority constraints and specify the interventions needed by public policy actions, we broadly classify the adaptation actions into six different adaptation pathways depending on their impact pathways toward building adaptive capacity and associated co-benefits (Table 7.1). The first five are ex ante adaptation actions while the last is the ex-post pathway. However, even the ex-post actions require ex-ante preparation. The pathways are defined mainly based on impact management pathways. Adaptive capacity is created in four ways: (1) by absorbing the impacts of the shocks, (2) by protecting against the impacts of the shock, (3) by avoiding the shock or reducing exposure to the impacts of the shock, or (4) by transferring the adverse impacts of the shock to another party. The first two build adaptive capacity by absorbing shocks so that the shocks will not cause significant economic or social damage. However, the first pathway also helps to mitigate shocks by reducing greenhouse gas emissions in the form of carbon sequestration and methane emission reduction. The third pathway builds adaptive capacity by protecting a household or a system from shock. The fourth helps to skip the impacts of the shock by moving it from a vulnerable economic sector to a sector less exposed to climate shock. The last two build adaptive capacity by transferring the risk to a second party through market and nonmarket mechanisms.

Although the primary objective of adaptation actions is to build the adaptive capacity of households, communities, or economies, it is important to note that these actions have a wide range of co-benefits. As shown in Table 7.1, the six adaptation pathways generate varying co-benefits. Most of the co-benefits are related to economic benefits in the form of increasing productivity, economic transformation, wealth accumulation, and agribusiness development. The first and last pathways generate additional social benefits in the form of mitigating climate change and enhancing human dignity, solidarity, and nutrition for socially marginalized people. Cash transfers and emergency responses are widely recognized as good opportunities to combat malnutrition prevalence in chronically food-insecure and climate-vulnerable communities (Tiwari et al. 2016). Understanding these co-benefits helps to justify public interventions and investments in adaptation actions and to align adaptation actions with the priorities of public policymakers.

When defining adaptation pathways, it is also important to highlight constraints affecting the adoption and strategizing of public intervention actions, as shown in Table 7.2. The table shows how the adaptation pathways face different constraints, ranging from externalities to the exorbitant costs of adoption, to behavioral

TABLE 7.1—TYPOLOGY OF ADAPTATION ACTIONS

Adaptation actions	Examples	Impact pathways	Co-benefits
Climate-smart actions	Climate-smart agriculture, ecosystem restoration, efficient water management, energy transition	Reduction of shocks and absorption of shock impacts	Sustainably increased productivity, resilience capacity, mitigation
Intensification actions	Drought-tolerant crops, irrigation	Absorption of shock impacts	Increased productivity and triggering transformation
Asset-building actions	Infrastructure construction, food reserves, savings	Protection from the impacts of shocks	Wealth accumulation
Diversification actions	Value chain development, employment generation schemes, nonfarm activities	Avoidance of impacts of shocks	Economic transformation
Risk transfer actions	Weather-based insurance	Market-based transfer of risks	Agribusiness development
Ex post response actions	Cash transfers, emergency responses	Social transfer of risks	Enhanced human dignity, solidarity, nutrition

Source: Authors' compilation.

TABLE 7.2—CONSTRAINTS TO ADOPTION AND NECESSARY INTERVENTIONS ACROSS ADAPTATION PATHWAYS

Adaptation actions	Constraints to adoption	Strategic options to enhance adoption
Climate-smart actions	Adopters don't experience full benefits	Carbon trade, payment for environment services
Intensification actions	High sunk cost for research, extension, and development	Public–private partnership
Asset-building actions	High cost of public investment and behavioral resistance	Awareness campaign and political commitment
Diversification actions	Access to finance and markets; new skills for new activities	Focus on local and regional value chains and incubating micro, small, and medium enterprises
Risk transfer actions	Challenges of enforcement and high transaction costs	Empowerment of producers' organizations to participate in insurance intermediation
Ex post response actions	Burden on public finance and competition with long-term development activities	Linkage of transfers with productive activities; effective targeting

Source: Authors' compilation.

and capacity challenges among consumers, producers, and entrepreneurs. The adoption of adaptation options by smallholder producers and entrepreneurs is also strongly dependent on the functioning of social services and markets. Table 7.2 also outlines the strategic interventions needed to enhance the adoption of adaptation pathways by different actors. For example, the promotion of carbon trade and payment for environmental services are important strategic interventions for enhancing the adoption of climate-smart actions by smallholder producers. Unless farmers can feel the full benefits of their climate-smart actions, wider adoption of these options is very unlikely.

The Adoption and Effectiveness of Selected Adaptation Options

In this section, we explore the adoption and effectiveness of climate adaptation actions to build resilient agriculture. We aim to attract the attention of policymakers to areas where African countries are progressing well or where they are struggling. Owing to space and time constraints, we have focused on agriculture. Agriculture is the dominant sector in many countries and is severely affected by climate change, but at the same time, it contributes both to climate adaptation and to mitigation through carbon sinking and sequestration. Agriculture is also a priority sector in the NAPs of most African countries.

Climate adaptation in agriculture can be built either through enhancing the uptake of improved and sustainable agricultural practices or by transferring climate risk to financial institutions through weather-based agricultural insurance. Of the six adaptation pathways, the most dominant in agriculture are (1) climate-smart actions, (2) intensification actions, and (3) risk transfer actions. In this section, we track and examine selected agricultural adaptation interventions from within these categories:

- CSA and sustainable land management practices
- Expansion of irrigation
- Weather-based agricultural insurance

However, before we track the adoption and effectiveness of these adaptation actions, we review the resilience of agricultural households in Africa using data from the Comprehensive African Agriculture Development Program (CAADP) Biennial Review (BR) reports.

Resilience of African Agricultural Households

Comprehensive studies estimating the resilience of agricultural households to climate and weather-related shocks are scarce, with only a few vulnerability assessments conducted in select countries, as outlined in this chapter of the ATOR. Seeking to illuminate the extent of adaptation and resilience in African agriculture, we calculated the average number of farm households reportedly resilient to climate shocks in 2023 using CAADP BR data for the year 2022, encompassing 31 countries with reliable data, and representing approximately 919 million people on the continent.

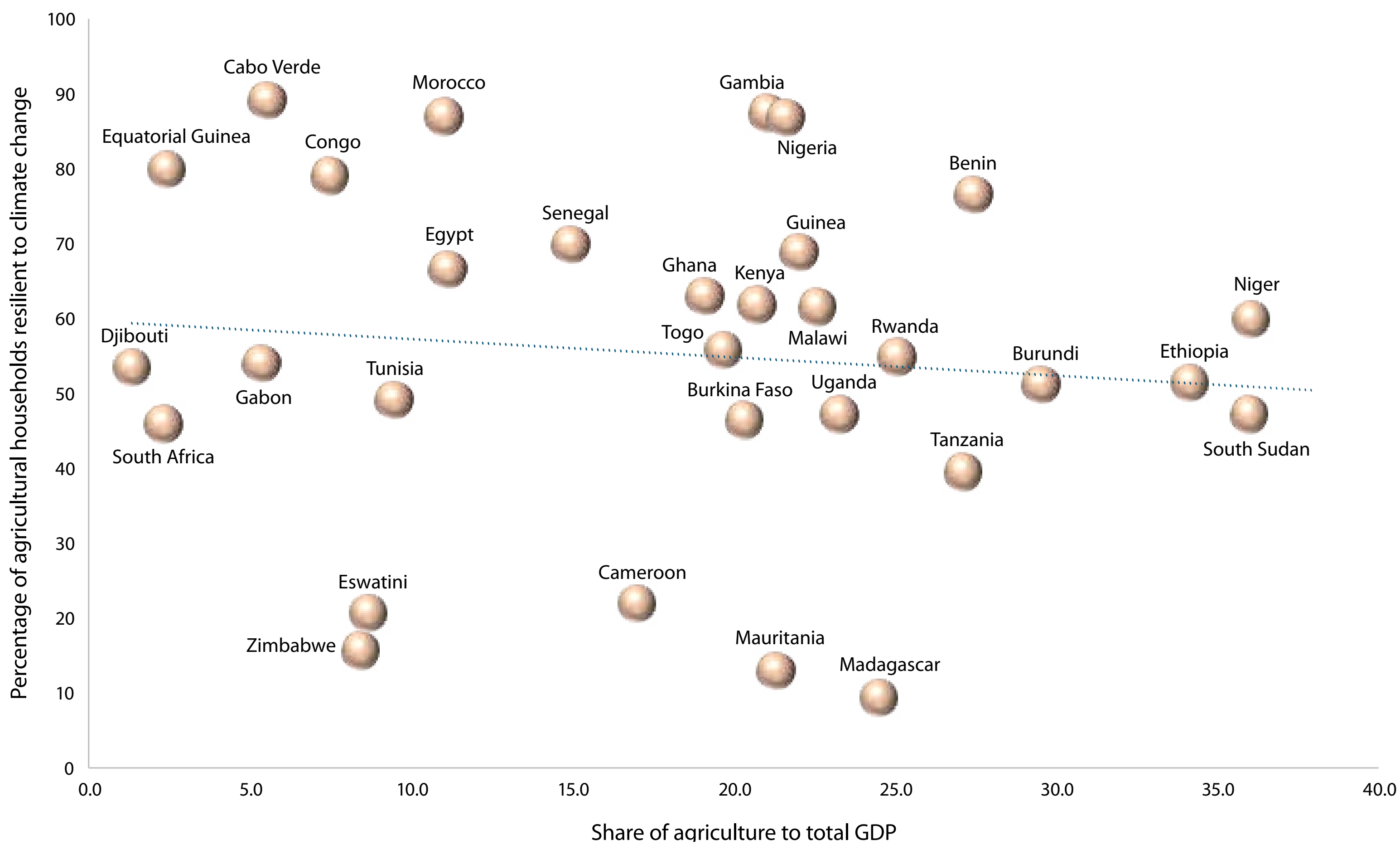
From this sample of 31 countries and a population-weighted average, it emerged that 60 percent of African agricultural households are resilient to climate change. This implies that 40 percent of such households are vulnerable to climate shocks. The resilience rate varies across countries: in the median country, 55 percent of agricultural households can be considered resilient, while in some nations, this figure plummets to as low as 10 percent. Among the 31 countries surveyed, 11 reported agricultural resilience levels of 50 percent or less, indicating that over half of their rural households remain vulnerable to climate shocks, jeopardizing their livelihoods.

It is pertinent to consider whether transitioning away from agriculture enhances the resilience of agricultural households. Figure 7.2 below illustrates the percentage of agricultural households resilient to shocks alongside the share of agriculture in total GDP. It suggests a weak correlation between agricultural resilience to climate shocks and the agricultural sector's contribution to the economy. In countries where agriculture makes up a large proportion of GDP, the sector appears less resilient, and vice versa, as evidenced by the downward-sloping trend line. This correlation could be linked to economic diversification toward nonagricultural sectors, enabling agricultural households to diversify their income streams through nonfarm activities. Climate change inflicts varying degrees of damage across sectors and economic activities, with agricultural incomes susceptible to drought while nonfarm incomes face market shocks stemming from extreme weather events. Nonetheless, nonfarm incomes and mining sectors exhibit greater resilience than other sectors to climate shocks. Thus, household and national-level economic diversification helps mitigate climate change–induced damage and fosters shock resilience.

However, the correlation depicted in Figure 7.2 is not robust. Some countries demonstrate significant levels of resilience despite the reliance of their GDP on agriculture. These countries prioritize the enhancement of agricultural resilience over transitioning away from agriculture, underscoring the necessity for countries to tailor their adaptation strategies to their specific contexts. While economic diversification may be economically viable for certain countries, for others the preferred strategy may be agricultural intensification through the adoption of climate-smart and intensification measures, as discussed earlier. In summary, transitioning away from agriculture is not a universal solution for all African countries.

We delved deeper into the relationship between the proportion of public expenditure allocated to agriculture within the total public budget and the percentage of agricultural households reportedly resilient to climate- and weather-related shocks. This analysis aimed to gauge the efficacy of public spending in fortifying agricultural resilience, utilizing cross-sectional data sourced from

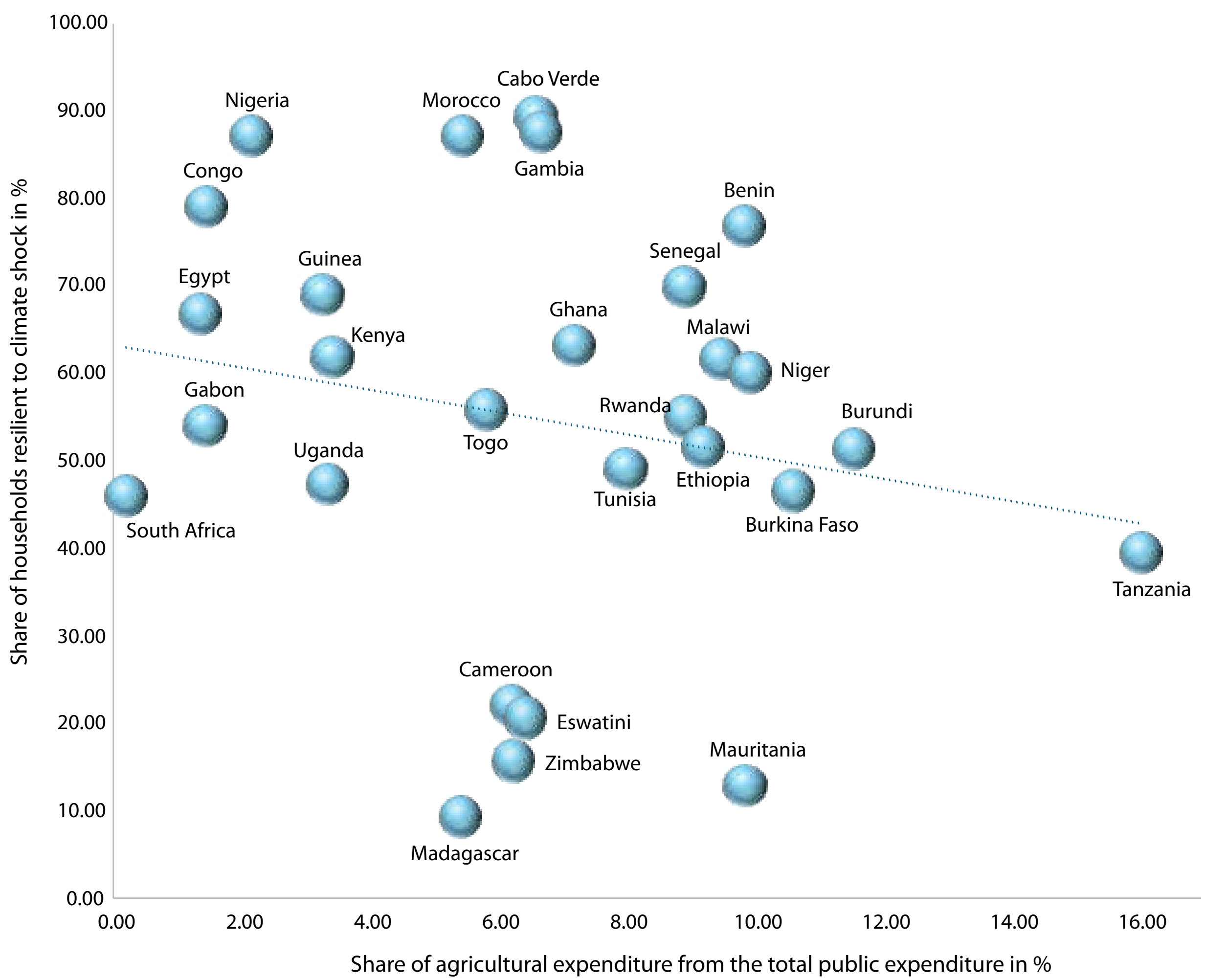
FIGURE 7.2—AGRICULTURAL RESILIENCE AND SHARE OF AGRICULTURE IN TOTAL GDP



Source: Authors' estimation based on the 2023 CAADP BR data (AU, CAADP, and AUDA-NEPAD 2024

CAADP BR. Surprisingly, our findings revealed a negative correlation, suggesting that nations allocating a larger portion of their budget to agriculture tend to exhibit lower levels of agricultural resilience (see Figure 7.3). Several factors could account for this unexpected outcome. Firstly, it is plausible that countries are directing their budgetary allocations not toward agricultural endeavors that bolster resilience but rather toward other agricultural investments with a lesser impact on enhancing agricultural adaptation. Secondly, the causal relationship might be reversed, implying that nations more susceptible to climate shocks might allocate a higher share of their budget to agriculture compared to less vulnerable counterparts. To mitigate such issues, we incorporated lag values (specifically from 2018 and 2020) of agricultural expenditure share and current resilience values from 2022. Consequently, the negative correlation likely stems from the ineffective allocation of agricultural expenditure in fostering climate-resilient agriculture. Considering the escalating threat posed by climate change, reevaluating the allocation of public expenditure toward climate-smart initiatives emerges as a crucial policy imperative for African nations.

FIGURE 7.3—PUBLIC AGRICULTURAL EXPENDITURE AND RESILIENCE OF AGRICULTURAL HOUSEHOLDS IN AFRICA



Source: Authors' estimation based CAADP BR data (AU, CAADP, and AUDA-NEPAD 2024).

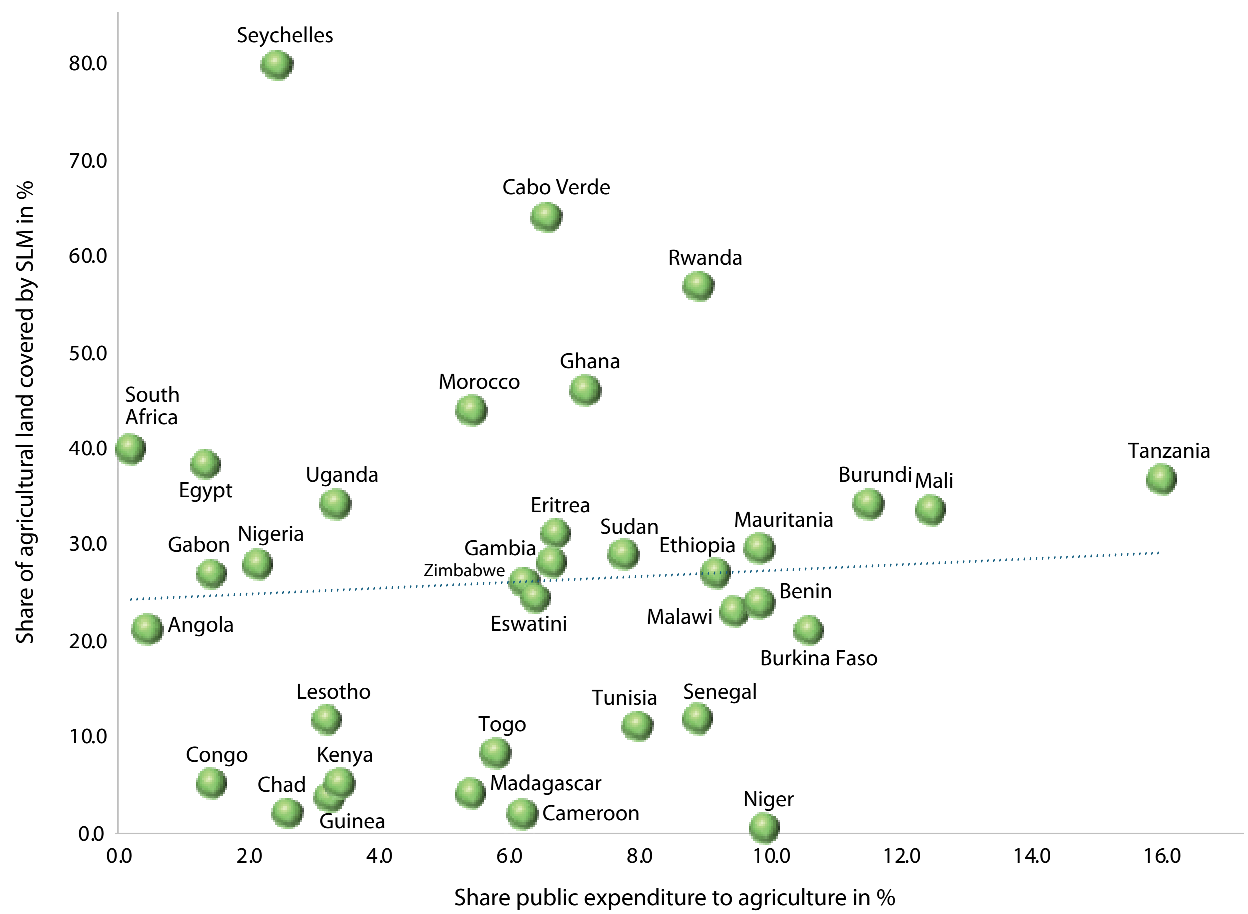
Climate-Smart Agricultural Practices

Numerous African countries are actively promoting CSA practices to enhance climate adaptation efforts. Rwanda, for instance, has introduced delineated and prioritized climate action programs, with CSA being a priority. The aim is to bolster adaptive capacity among a majority of rural households, as these bear the brunt of climate change impacts in the country. This prioritization aligns with the top priority intervention areas embraced by many African countries within their NAPs.

CSA can broadly be defined as farming practices, techniques, and systems that are designed to sustainably increase agricultural productivity and resilience to climate change, while also minimizing greenhouse gas emissions and preserving natural resources such as water and soil. It involves a combination of traditional knowledge and innovative approaches tailored to specific local conditions, aiming to ensure food security and mitigate the impacts of climate change on agriculture. CSA aims to achieve three important objectives: enhance resilience to climate change, promote sustainable land use, and improve agricultural productivity in the face of changing climate conditions.

Despite the importance of CSA in mitigating and adapting to the adverse effects of climate change, the adoption of CSA practices in Africa is marred by several problems. Some even question the economic viability and profitability of such practices for smallholder producers in Africa. A study by the CGIAR Research Program on Climate Change, Agriculture and Food Security indicates that though the adoption of CSA practices imposes additional costs, the benefits outweigh these costs, with varying rates of financial profitability across different CSA practices (Ng'ang'a et al. 2020). The most widely accepted consensus that comes out of these studies is that the economic benefit of CSA practices is higher if adaptation actions are adopted as a complete package. The adoption intensity of CSA practices has shown a positive and significant impact on household income, net farm income, and income diversity. Those farmers who adopted the full package of CSA practices obtained higher incomes than those who adopted only a few of the practices (Sang et al. 2024). At the national level, adopting CSA on 25 percent of Ethiopia's maize and wheat land was found to increase annual GDP by an average of 0.18 percent and to reduce the national poverty rate by 0.15 percentage points (Komarek et al. 2019).

FIGURE 7.4—PUBLIC EXPENDITURE IN AGRICULTURE AND AGRICULTURAL LAND COVERED BY SUSTAINABLE LAND MANAGEMENT



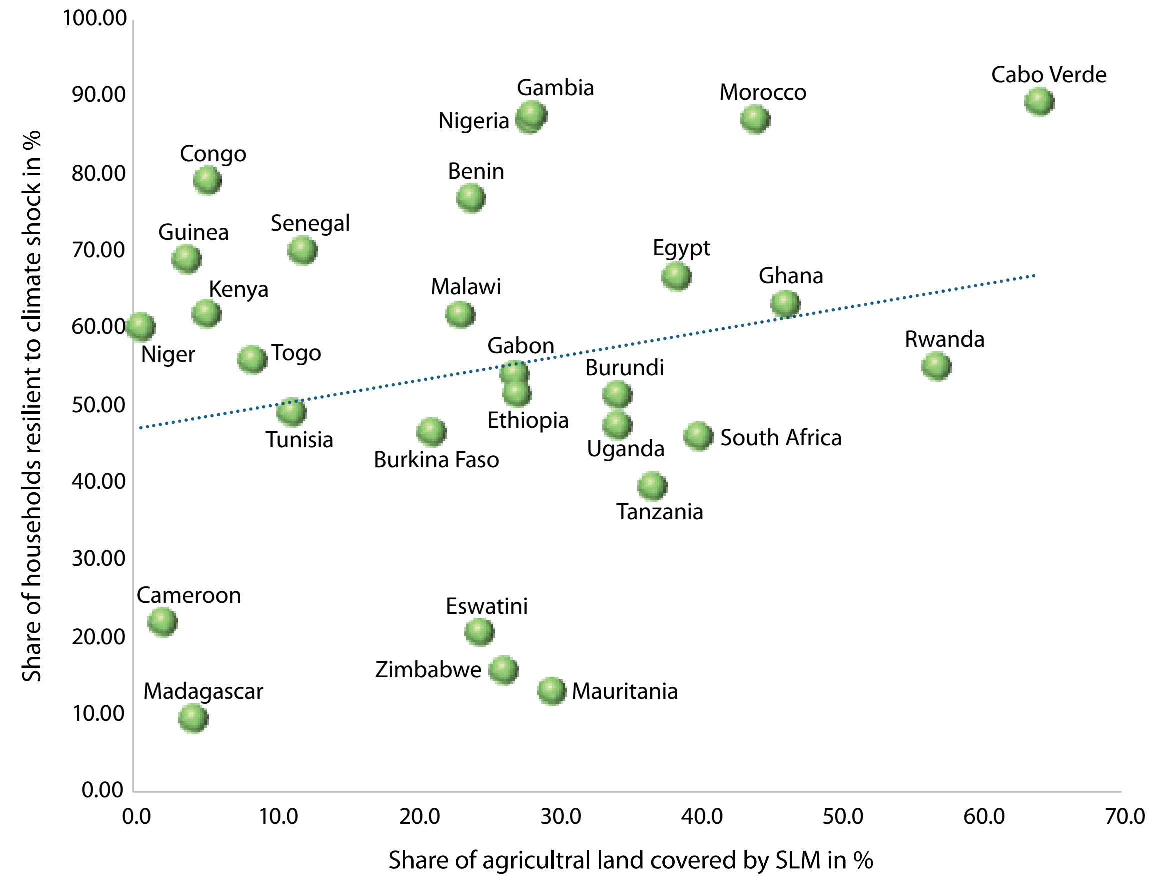
Source: Authors' estimation based on CAADP BR data (AU, CAADP, and AUDA-NEPAD 2024).

Unfortunately, the adoption of CSA practices is inversely correlated with their profitability (Nkonya and Koo 2017). Therefore, in addition to assessing the economic viability of CSA practices, it is crucial to acknowledge the institutional and infrastructural barriers impacting their adoption and effectiveness. Figure 7.4 illustrates the correlation between public agricultural expenditure and the agricultural area covered by sustainable land management, including

CSA practices. However, the data reveal a remarkably weak and nearly insignificant correlation. This implies that there is no discernible difference in the proportion of agricultural land covered by sustainable land management practices among countries, regardless of their levels of public agricultural expenditure. It suggests that current public agricultural investments have yet to yield observable sustainability improvements. This observation might elucidate the weak correlation between public agricultural expenditure and the area covered by sustainable land management, as depicted in Figure 7.4. While it is commendable that African governments are committed to allocating sufficient budgets to agriculture, it is imperative to emphasize the efficient allocation of these resources within agricultural activities.

We further examined the effectiveness of CSA practices in enhancing agricultural resilience, utilizing the same CAADP BR dataset. We aimed to illustrate the relevance of CSA in fortifying household-level economic resilience. As anticipated, our findings reveal compelling evidence of a positive correlation between the proportion of agricultural land covered by sustainable land management practices and the percentage of agricultural households resilient to climate shocks (see Figure 7.5). On average, countries that have made greater investments in CSA demonstrate a higher proportion of resilient rural households. However, it is noteworthy that the extent of land covered by CSA practices remains relatively low. Among the 35 countries analyzed, only three have managed to cover more than 50 percent of their agricultural lands with sustainable land management practices. This highlights the need for concerted efforts to scale up the adoption of CSA practices to maximize their impact on agricultural resilience.

FIGURE 7.5—INVESTMENT IN SUSTAINABLE LAND MANAGEMENT AND AGRICULTURAL RESILIENCE TO CLIMATE SHOCK

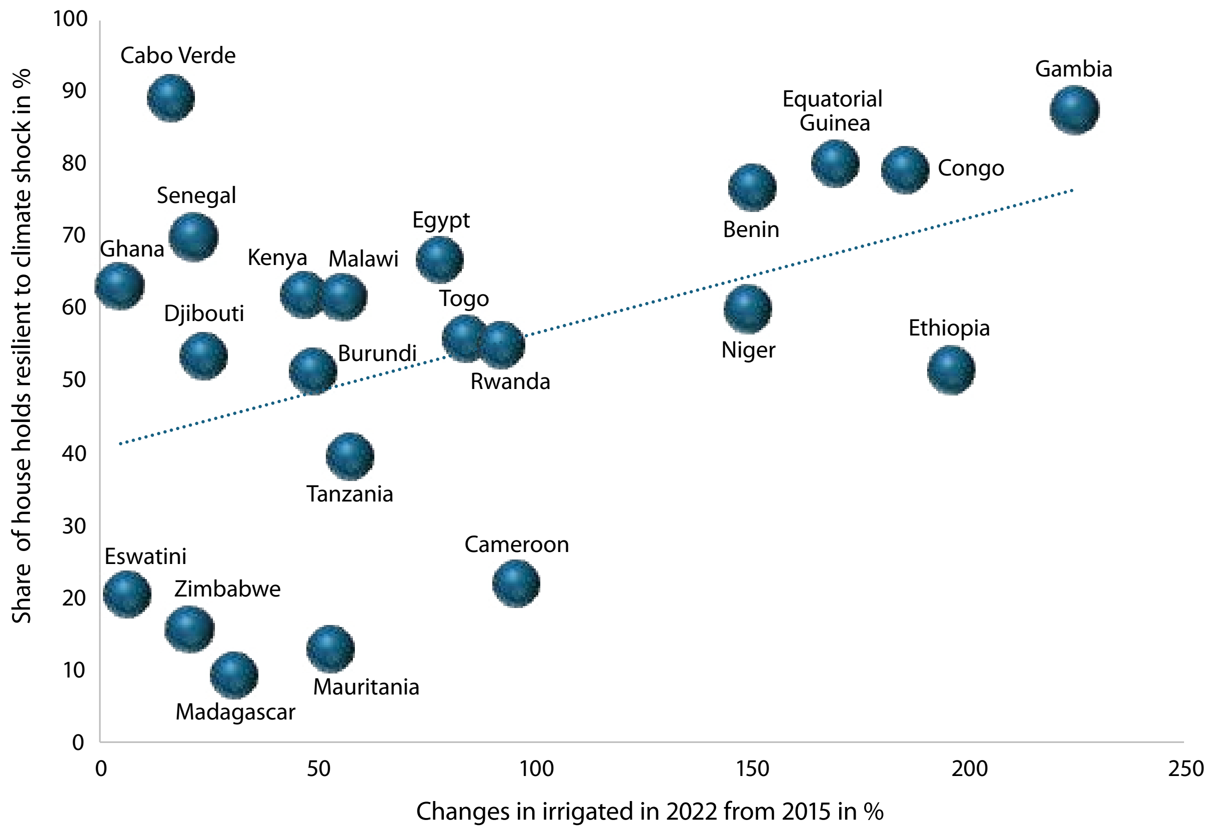


Source: Authors' estimation based on CAADP BR data.
Note: SLM = sustainable land management.

Irrigation investments

There is no denying the pivotal role of irrigation in fortifying agricultural resilience, particularly in regions susceptible to drought or unpredictable rainfall patterns. By offering a reliable water supply, irrigation aids farmers in mitigating the impacts of climate change, ensuring crops receive sufficient moisture and

FIGURE 7.6—INVESTMENT IN IRRIGATION AND THE RESILIENCE OF AGRICULTURAL HOUSEHOLDS TO CLIMATE SHOCK



Source: Authors' estimation based on the 2019, 2021, and 2023 CAADP BR data.

thereby reducing vulnerability to water scarcity while stabilizing yields. Moreover, the adoption of modern irrigation techniques such as drip and precision irrigation hold promise in optimizing water usage, fostering soil health, and minimizing environmental degradation, thus further bolstering agricultural resilience.

As depicted in Figure 7.6, our analysis reveals a robust correlation between investments in irrigation, quantified by the growth rate of land under irrigated agriculture, and the resilience of agricultural households. This correlation underscores the significance of prioritizing irrigation infrastructure development as a way of enhancing agricultural resilience in the face of climate variability.

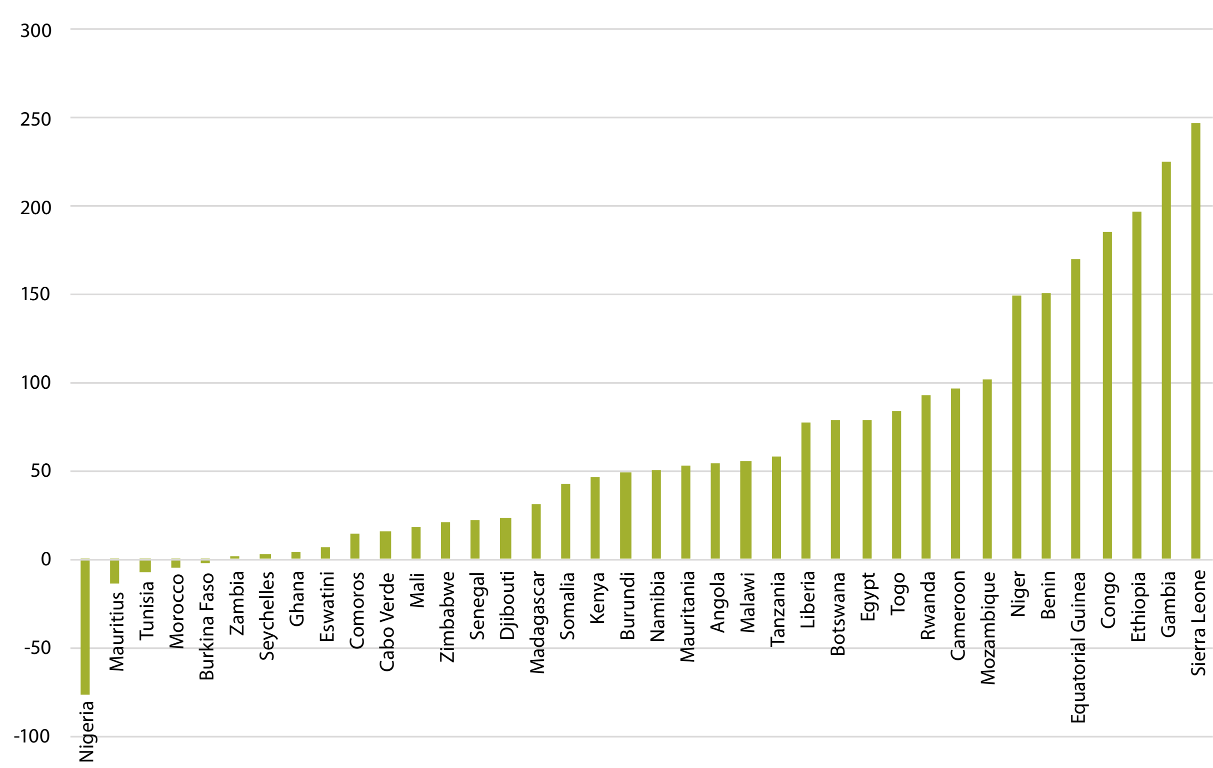
However, the pace of growth in irrigation investment falls short of meeting the necessary threshold to effectively build resilience in many countries. Figure 7.7 illustrates the changes in irrigated agricultural lands between 2022 and 2015, based on the 2023 CAADP BR data. Among the 38 countries analyzed, only 8 had managed to double or more than double their irrigated area by 2022. These countries have made substantial investments in irrigation and are on track to meet the targets set by the AU.

However, a significant portion of countries are lagging in irrigation investment. The median country in Africa has only been able to increase its irrigated area by approximately 50 percent over seven years, with an annual growth rate of 7 percent. In nine countries, the annual growth rate is less than 1 percent. Additionally, a few countries have experienced a decline in their areas of irrigated land. This decline could be attributed to data discrepancies or the obsolescence of existing irrigation schemes, rendering them unusable.

Expanding the area covered by irrigation is undoubtedly a crucial policy objective. However, it is equally imperative to address the issue of maintenance and upgrading existing irrigation schemes to ensure their continued effectiveness and sustainability.

Another crucial consideration regarding investment in irrigation in Africa is the feasibility and scalability of irrigation for smallholder producers. A study conducted by AKADEMIYA2063 in collaboration with FAO in Burkina Faso and Niger aimed to explore the feasibility and scalability of small-scale irrigation. The findings revealed that significant amounts of agricultural areas could be developed for small-scale irrigation, yielding positive and significant net economic returns. Table 7.3 provides a summary of the area size that can feasibly be developed for small-scale irrigation and the net returns achievable per unit of area under different irrigation technologies.

FIGURE 7.7—PERCENTAGE CHANGES IN IRRIGATED AREAS FROM 2015 TO 2022



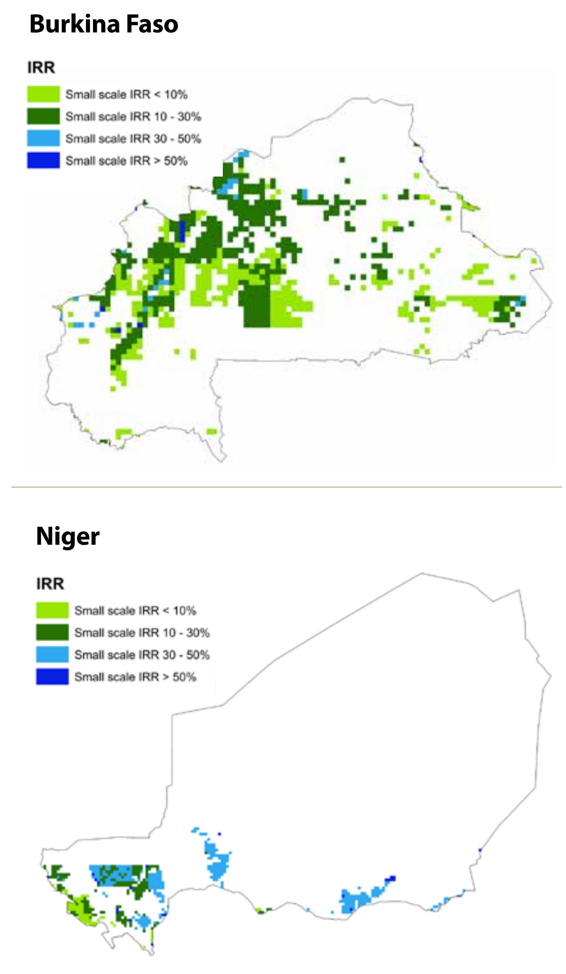
Source: Authors' estimation based on the 2019, 2021, and 2023 CAADP BR data.

TABLE 7.3—POTENTIAL IRRIGATION AREAS IN BURKINA FASO AND NIGER

Adaptability indicators	Treadle pumps	Motor pumps	Small reservoirs	Communal river diversions
Burkina Faso				
Application area (thousands of ha)	849	1,066	572	632
Net income (US$ per ha per year)	530.04	506.57	646.85	189.87
Net income (US$ per 100m^3 of water)	21.13	20.85	20.90	6.59
Niger				
Application area (thousands of ha)	133	136	98	6
Net income (US$ per ha per year)	827.07	808.82	714.29	666.67
Net income (US$ per 100m^3 of water)	91.67	91.67	46.67	20.00

Source: Tadesse et al. 2024a; Tadesse et al. 2024b.
Note: ha = hectare.

FIGURE 7.8—GEOGRAPHICAL DISTRIBUTION AND FEASIBILITY OF SMALL-SCALE IRRIGATION IN BURKINA FASO AND NIGER



Source: Tadesse et al. 2024a; Tadesse et al. 2024b.
Note: IRR stands for Internal Rate of Return

The potential and feasibility of irrigated lands extend across wider geographic areas, with significant implications for income distribution and the development of value chains, as shown in Figure 7.8. Based on these case studies, it appears that African countries possess substantial amounts of land with potential for irrigation development tailored to smallholder producers, which would enable them to fortify their agriculture against climate shocks. Harnessing this potential warrants the highest possible policy attention if the agricultural sector is to adapt effectively to the changing socioeconomic and biophysical environment.

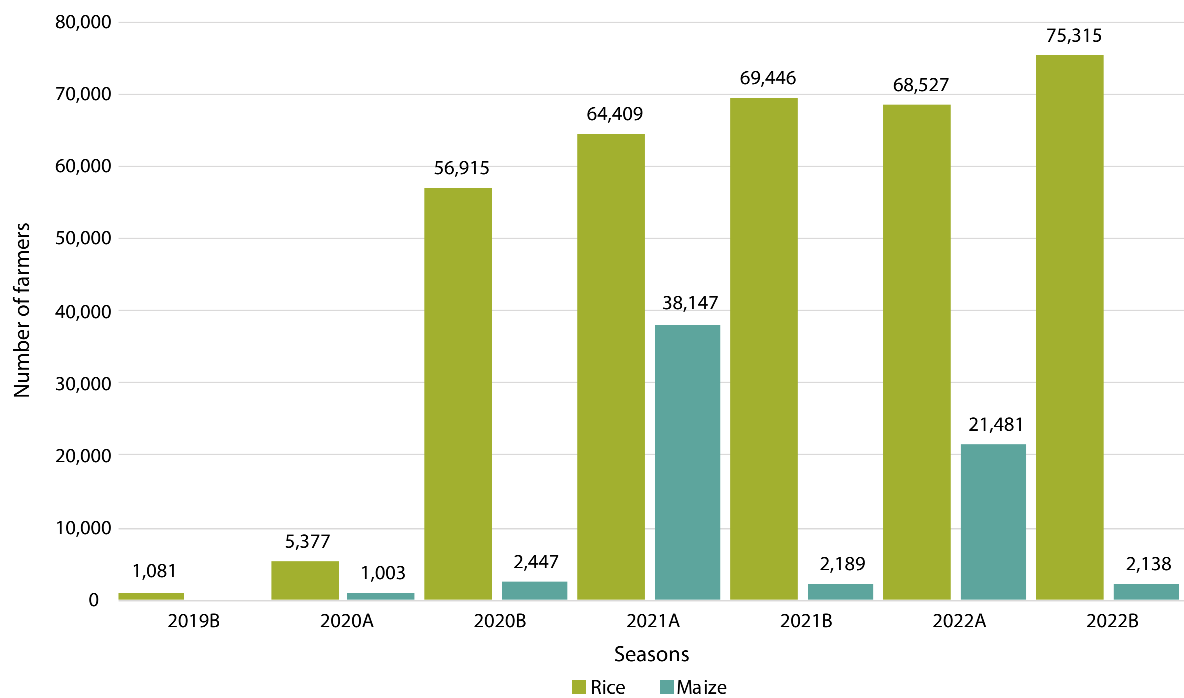
The State of Weather-Based Agricultural Insurance in Africa

Agricultural insurance is a valuable tool for farmers to manage risks that are beyond their control on the farm (World Bank 2019). Access to such insurance can help smallholder farmers deal with losses from climate change (Weber 2019). Different types of agricultural insurance include indemnity-based crop insurance, such as named peril and multiple peril crop insurance, as well as index-based insurance, such as index-based livestock insurance, and weather index insurance (Shumba 2022). All these insurance options are an essential way for farmers to protect themselves from climate change–related losses (Mcleman and Smit 2006). However, insurance products are not widely accessible or affordable for farmers in developing countries, particularly in Africa, where small-scale and subsistence farmers are most vulnerable to climate change risks (Raithatha and Priebe 2020). Limited access to insurance therefore has a significant impact on African agricultural producers who rely on rain-fed agriculture (Elum and Simonyan 2016).

There are a mix of benefits and challenges associated with weather-based agricultural insurance in Africa. While insurance can minimize contract problems, provide faster payouts for crop damage, and increase farmers' investment in agricultural inputs, coverage and uptake remain low. In many African countries, agricultural insurance coverage does not exceed more than 1 percent. Rwanda, for example, has introduced crop and livestock insurance for smallholder farmers to protect them from shocks. Its National Agricultural Insurance Scheme (NAIS) subsidizes 40 percent of the insurance premium, so farmers need to cover only 60 percent.

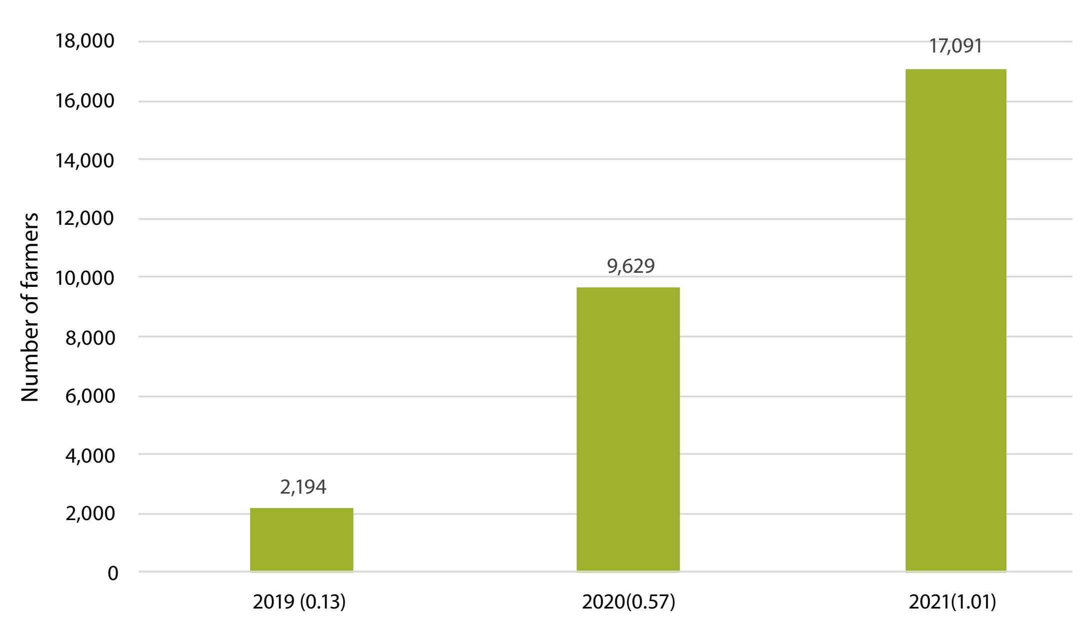
Data from Rwanda's Ministry of Agriculture and Animal Resources indicate that the number of farmers being covered by NAIS is increasing over time (Figure 7.9). Rice and maize are the most widely insured crops, followed by Irish potatoes. While the number of rice farmers purchasing insurance is increasing, the number of maize farmers with insurance oscillates between seasons. The highest rates of insurance for maize farmers were recorded during the first season of 2021. More than 75,000 rice farmers (3.6 percent of the total crop farmers) have purchased insurance through NAIS. However, there is less uptake of livestock insurance as a way of mitigating the risk of livestock death. About 17,000 farmers

FIGURE 7.9—FARMERS WHO PURCHASED CROP INSURANCE THROUGH THE NATIONAL AGRICULTURAL INSURANCE SCHEME IN RWANDA



Source: MINAGRI 2022.

FIGURE 7.10—NUMBER OF FARMERS WHO HAVE PURCHASED LIVESTOCK INSURANCE IN RWANDA



Source: MINAGRI 2022.
Note: Numbers in the parenthesis refer to the share of farmers who purchased livestock insurance.

purchased livestock insurance through NAIS in 2021, which is close to 1.01 percent of the total number of livestock keepers in Rwanda (Figure 7.10).

The challenges associated with expanding agricultural insurance include dealing with climate features such as large spatiotemporal rainfall variability, solving trade-offs between protection and the cost of premiums, lack of stakeholder involvement in insurance product analysis, poor understanding of crop insurance, inability to pay premiums, rigid enrollment criteria, uncertainty in cash flows, and inadequate knowledge of farmers' risk perception. These factors all contribute to the complexity of the agricultural insurance landscape in Africa (Fonta et al. 2018). The high transaction costs associated with contract enforcement among smallholder producers make the expansion and sustainability of weather-based insurance for African farmers more difficult. A study in Nigeria indicates that the country's agricultural insurance uptake is low due to the underdevelopment and ineffectiveness of formal insurance markets in many developing countries. Factors such as high administrative costs, moral hazard, adverse selection, and protracted delays in indemnity payment discourage the utilization of this type of insurance (Aina et al. 2024).

Various efforts are being made to develop and scale up weather index-based insurance products in Africa. Syngenta Foundation/UAP Insurance is developing SMS-based mobile applications to assist in scaling up insurance products for drought or excessive rainfall in Kenya. PlaNet Guarantee is implementing index-based insurance products in Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, Senegal, and Togo through the International Bank for Reconstruction and Development (World Bank 2011). MicroEnsure is developing local capacity and a favorable environment to reach low-income people with flexible, affordable, and responsive weather index insurance in Rwanda. In Kenya, index-based livestock insurance is designed to protect Kenyan pastoralists from drought-related asset losses.

Raising awareness and capacity within producer organizations (as intermediaries between insurance suppliers and smallholder producers) can be an effective way of sustainably scaling up agricultural insurance in Africa. The involvement of producer organizations helps to minimize transaction costs by reducing information asymmetry as well as increasing bargaining power for farmers so that they pay the lowest possible insurance premium. It also helps to create economies of scale for insurance service providers. The future of weather-based agricultural insurance in Africa is therefore directly linked to the capacity and effectiveness of smallholder producer organizations and associations.

The Challenges of Building Climate Resilience and Adaptation

A recent meta-analysis suggests that a wide range of factors affect African farmers' decisions on whether or not to adopt improved agricultural practices (Arslan et al. 2022). Of all the determinants, factors related to access to extension, information, farmer group participation, and credit are more significant and consistent than other factors. Access to general information (as opposed to narrowly focused practice-specific information) and farmer group participation increase adoption most consistently across a range of farming technologies and contexts. System-level constraints are more significant than farm-level constraints as they affect the overall capacity of a country to implement adaptation actions and build adaptive capacity. A study by Williams and others (2021) indicates that technological and institutional factors are the major system-level barriers to implementing adaptation actions. In this section, we review the most important challenges related to expanding the implementation of NAPs in Africa identified in these studies and other public discussions.

Adaptation Finance in Africa

The role of risk finance in facilitating adaptation cannot be overstated. In the past decade, climate finance directed toward Africa has notably increased, totaling around $26.4 billion in 2018 (GCA 2022). This surge reflects a growing acknowledgment of the urgent need to bolster regional adaptation efforts. Multilateral funds such as the Green Climate Fund have been pivotal in supporting adaptation projects in Africa, allocating more than $3.5 billion for resilience and adaptation (Fenton et al. 2017). Regional development banks such as the African Development Bank have also initiated targeted programs such as the Africa Climate Change Fund to address adaptation needs. Additionally, private sector involvement in climate resilience is expanding, with investments in adaptation-focused projects rising, particularly in emerging markets in Africa (IFC 2017). Innovative financing mechanisms such as the African Risk Capacity are being explored by African countries to mobilize extra resources for adaptation efforts. These developments underscore a growing momentum toward allocating funds for adaptation actions in Africa, propelled by governmental and global institutional initiatives.

Despite this progress in developing adaptation and risk finance in Africa, significant challenges persist. These include limited financial resources, weak institutional capacity, fragmented governance structures, and insufficient data and information. Consequently, Africa still grapples with a substantial funding gap for climate adaptation, with an estimated $579 billion required by 2030 across 51 African countries. This far exceeds the annual outlay of $11.4 billion observed in 2019 and 2020. While most adaptation funding stems from the public sector, unlocking a broader array of potential actors necessitates creating an environment conducive to investment and scaling up innovative finance instruments (GCA 2022).

Opportunities do exist to harness domestic and international funding, forge stronger partnerships, leverage technology, and integrate adaptation into broader development agendas. New developments are emerging in response to the need to specifically allocate funds for adaptation actions by governments and global institutions. However, the outcomes of the 28th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP28) presented a mixed bag for Africa. While notable successes were achieved in areas such as addressing loss and damage, bolstering climate finance, advancing adaptation measures, and promoting renewable energy initiatives, there is still a palpable gap to overcome to meet the continent's ambitious goals for combating climate change and fostering sustainable development. Despite a commendable effort that resulted in the mobilization of more than $85 billion aimed at curbing temperature escalation, significant funding shortfalls persist, particularly in crucial areas such as adaptation, which is indispensable to building Africa's resilience against and response to climate-related challenges (Shirley, Deme, and Onyango 2023).

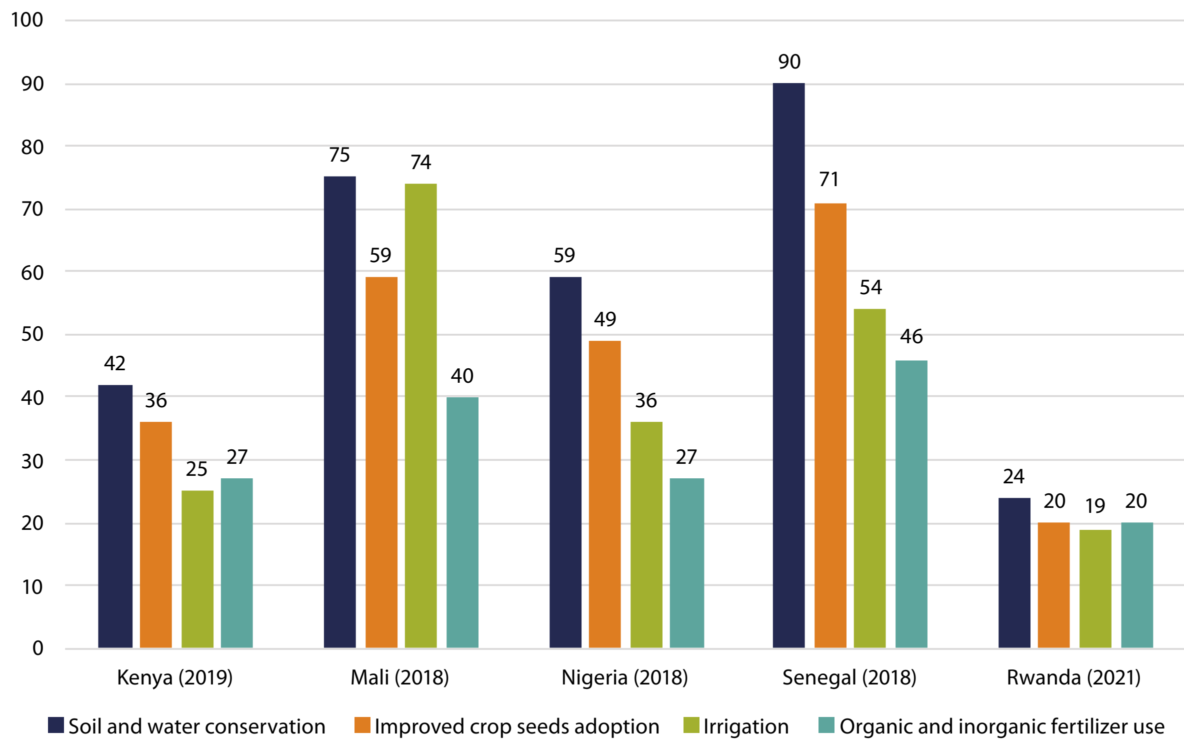
The establishment of the Loss and Damage Fund, created at COP27 in Egypt, backed by $792 million in commitments, marks a positive stride forward. However, this sum falls short of the estimated $290 to 440 billion needed to comprehensively address Africa's loss and damage requirements (Hemingway Jaynes 2023). Africa also needs enhanced support to attain its climate finance targets, especially in fulfilling the New Collective Quantified Goal on Climate Finance commitments and accessing domestic funds effectively (Guzmán et al. 2022).

Scaling of Adaptation Actions

Several interventions have been piloted and found successful in reducing the adverse impacts of climate risk on agricultural production and rural livelihoods in Africa. However, the extent of scale-up and scale-out is very limited. The adverse effect of climate change will be effectively reversed only if adaptation actions are implemented at scale to cover wider areas and to address a significant number of vulnerable groups. Unless countries can scale up best practices and invest to the extent that generates economies of scale, it is unlikely that any meaningful resilience will be achieved.

Figure 7.11 shows the extent of scale-up needed to fully reverse the lost agricultural production and productivity attributed to climate change in selected countries: Kenya, Mali, Nigeria, Rwanda, and Senegal. For example, to fully recover lost agricultural production in Mali, the total area covered by

FIGURE 7.11—SCALE-UP REQUIRED TO COMPENSATE FOR THE IMPACT OF CLIMATE CHANGE, IN PERCENTAGES



Source: Authors' compilation from economy-wide modeling by AKADEMIYA2063.
Note: Numbers in parentheses indicate baseline years.

soil and water conservation practices in 2018 must be scaled up by 75 percent. Alternatively, it would be possible to reverse the adverse impacts of climate change if Mali increased the area under irrigation by 74 percent. This means that if Mali's agricultural sector is to remain resilient and avoid a significant reduction in agricultural GDP, the country must significantly increase its level of investment in scaling existing adaptation interventions. This interpretation applies to other countries as well.

Effectiveness of Climate Information Services

Africa's vulnerability to climate change impacts has led to a growing focus on weather and climate information services (WCIS) in recent years (Hansen et al. 2022; Ofoegbu and New 2022). These services provide valuable climate-related information to various stakeholders, including farmers, policymakers, and humanitarian organizations, to help them make informed decisions and build resilience to climate variability and change. A variety of innovations have been developed by a wide range of global and regional institutions to provide predictive climate information services. However, the level of uptake and impact of these services is not yet significant.

The use of WCIS in Africa varies across regions, sectors, and seasons. In Senegal, for example, at the beginning of the rainy season, nearly 80 percent of farmers were found to have used WCIS to decide on sowing dates and about 60 percent to decide on crop varieties. In the middle of the growing season, about 70 percent used WCIS to decide on fertilizer application dates (Ouedraogo et al. 2021). Factors limiting the use of WCIS include accessibility of information, communication channels, awareness, education, and socioeconomic conditions. In some areas, particularly where WCIS is well established and tailored to local needs, uptake has been significant, leading to positive impacts on livelihoods, agriculture, water management, and disaster risk reduction.

Several studies have documented the impacts of climate information services in Africa (Djido et al. 2021). These impacts range from improved agricultural productivity and food security to enhanced water resource management and reduced vulnerability to climate-related disasters. For example, farmers who receive timely climate information are better able to plan their planting and harvesting activities, leading to increased yields and incomes. Similarly, early warning systems based on climate information help communities prepare for and respond to extreme weather events, reducing loss of life and property damage. However, these impacts are very much context-specific and limited to certain areas and farmers.

Governance of Adaptation Actions

Collaboration among communities, governments, and both private and nonprofit organizations is paramount for effective climate adaptation actions. However, managing this collaboration poses significant challenges, and it often proves less effective in practice. Many African countries have established multisectoral climate change leadership and technical working groups, meticulously designed to incorporate representatives from government ministries, civil societies, donor groups, academia, and the private sector, with clearly outlined objectives.

Despite their well-defined structures and articulated objectives, these working groups frequently lack practical effectiveness and influence. Meetings are irregular, and when they occur, discussions tend to focus on less strategic and binding issues, such as approving or validating policy documents. Consequently, they struggle to effectively coordinate activities, prevent redundancies, and design collaborative efforts.

Recognizing this challenge, some countries, such as Rwanda, have taken proactive steps to address it by reorganizing their climate change working groups based on a programmatic approach. This approach aims to consolidate smaller climate change projects into selected flagship programs that can be implemented at scale. Moreover, it facilitates the alignment of stakeholders working in the same programmatic area, enabling them to contribute to the design, implementation, and evaluation of these programs. This strategic restructuring holds promise for enhancing the effectiveness and impact of collaborative climate adaptation efforts.

Apart from the stakeholder coordination challenge, some adaptation action requires a governance system that involves the active and genuine participation of local communities to make sure that the actions result in sustainable outcomes. Typical examples are adaptation actions related to ecosystem management. Common ecosystem management practices in Africa include community-based natural resource management, protected area management, sustainable forestry, agroecology, and watershed management. These approaches often involve collaboration between local communities, governments, and organizations to balance conservation with human needs, promoting biodiversity, sustainable resource use, and resilience to environmental changes.

This suggests that if countries wish to be effective in implementing adaptation plans and achieving sustainable outcomes, they should commit to revisiting and strengthening their climate change governance systems. An effective system provides the framework, policies, and mechanisms needed to address the impacts of climate change at local, national, and international levels. Good governance ensures coordination among stakeholders, allocates resources efficiently, fosters innovation, and promotes accountability, all of which are essential for successful adaptation efforts. Without proper governance structures in place, adaptation actions may be disjointed, insufficient, or ineffective in addressing the challenges posed by climate change.

Tracking Adaptation Actions and Outcomes

As discussed in Section 2, unlike measuring mitigation, it is very difficult to measure adaptation capacity through a single indicator. Measuring climate adaptation capacity poses several challenges due to the multiplicity of adaptation changes required to build resilience. One major challenge lies in establishing comprehensive and standardized metrics to assess adaptation progress across different regions and sectors. Adaptation strategies vary widely based on local contexts, making it difficult to create universal measurement criteria. Additionally, attributing specific outcomes solely to adaptation actions can be complex, as various factors contribute to climate resilience. Any indicator for measuring adaptation should be a composite indicator that captures all aspects of structural adjustments through the adoption of technologies, institutional innovation, and infrastructural developments as well as behavioral changes. Currently, such a metric does not exist. Limited data availability, high cost of data collection, and the long-term nature of adaptation efforts further complicate measurement, often resulting in difficulty tracking and evaluating the effectiveness of implemented adaptation measures.

The presence of several climate change initiatives with varying monitoring and evaluation systems also makes the measurement and tracking of adaptation actions and outcomes very challenging and inconsistent. The different initiatives use different performance indicators and targets, making it complicated to perform comparisons across countries and years. A consistent and comprehensive central database system that can serve as a source for all initiatives and tracking needs across all countries would help to address this.

Conclusion and Recommendations

This chapter has undertaken a comprehensive examination of the conceptual and practical dimensions surrounding climate adaptation efforts in Africa, with a particular emphasis on the agricultural sector. Agriculture is not only the backbone of many African economies and livelihoods but is also the sector most profoundly impacted by climate variability and extreme events. As a result, almost all African countries have identified agriculture as a priority sector for their climate adaptation action. However, our analysis has revealed that, despite noteworthy advancements under several Malabo indicators, African agriculture remains susceptible and insufficiently resilient to climate shocks. Approximately 4 out of 10 agricultural households remain vulnerable to these disruptions. Moreover, the shift away from agriculture and the proportion of public expenditure allocated to the sector is weakly correlated with enhancements to agricultural resilience.

Though the level of implementation and investment in agricultural adaptation remains disconcertingly low, Africa has demonstrated commitment through the development and submission of nationally determined contributions and elaborated national adaptation plans. These plans encompass a diverse array of adaptation actions, which can be categorized into six adaptation pathways based on their impact pathways and co-benefits. Such categorization aids countries in prioritizing actions relevant to their specific contexts, enhancing the effectiveness of implementation efforts.

Bridging the gap between plans and actions requires concerted efforts and strategic interventions. Drawing from our analysis, several recommendations emerge for shaping the post-Malabo climate adaptation agenda. These recommendations are as follows:

1. **Align continental and national adaptation plans and tracking systems.** Harmonizing climate adaptation strategies and plans at regional, continental, and national levels is paramount. Consolidating these efforts under a unified NAP facilitates prioritization and implementation across sectors, while also streamlining tracking mechanisms for adaptation ambitions and actions.
2. **Strengthen institutional capacity.** Building technical expertise, institutional structures, and coordination mechanisms is critical for effective adaptation planning and implementation. Governments should invest in capacity-building efforts spanning national, regional, and local levels to support adaptation initiatives comprehensively.
3. **Support knowledge sharing and capacity development.** Facilitate knowledge sharing and capacity development across nations, communities, and stakeholders to increase understanding of climate risks and adaptation choices. This might entail fostering South–South collaboration, peer learning networks, and access to climate knowledge and technology. The capacity building should focus on investing in research and development for generating technologies and innovations that help to enhance adaptations at farm and community levels.
4. **Enhance climate information services.** Timely and reliable climate information is indispensable for informed decision-making and planning. Policies should prioritize the development and dissemination of climate information services tailored to local needs, encompassing early warning systems, risk assessments, and sector-specific forecasts.
5. **Mainstream adaptation into sectoral policies.** Integrating adaptation considerations into sectoral policies and planning processes is essential for fostering climate resilience across key sectors. Governments should mainstream adaptation into sectoral policies, investment plans, and regulatory frameworks to ensure climate-compatible development.
6. **Boost community-based adaptation actions.** Supporting community-led adaptation initiatives strengthens local resilience and empowers vulnerable communities. Policies should promote participatory approaches, local knowledge systems, and community-led adaptation planning processes, with a focus on marginalized groups.
7. **Enhance financial mechanisms for adaptation**. Mobilizing adequate and predictable finance is crucial for effective adaptation implementation. Policies should prioritize the allocation of public funds for adaptation, explore innovative financing mechanisms, and enhance access to international climate finance sources.

By heeding these recommendations and adopting a holistic approach to climate adaptation, Africa can bolster its resilience to climate change, safeguard livelihoods, and foster sustainable development in the face of evolving climate challenges.

CHAPTER 8

A Nutrition-Sensitive Circular Bioeconomy for Food Systems Transformation in Africa

Vincent Abe-Inge, Raphael Aidoo, Ebenezer Miezah Kwofie, and John M. Ulimwengu

Introduction

Africa's commitment to creating a sustainable and self-sufficient economy for its rapidly growing population has led to programmatic actions aimed at meeting local food, energy, and material demands sustainably and without compromising planetary boundaries (Africa Business Page 2022; Agri SA 2023). The bioeconomy has become a primary focus of this transformative blueprint, generally positioned as a vehicle for generating and using bioresources in meeting local demands for abundance, sustainable goods, and services (Gatune, Ozor, and Oriama 2021; Malabo Montpellier Panel 2022). However, the implementation momentum of the bioeconomy is incumbent on a well-planned and objective-oriented policy framework that supports generation of scientific evidence and reasonable investment structures, among other requirements for implementation (East African Community 2022; Pachón et al. 2018).

This chapter provides research-based evidence on the potential for leveraging the African bioeconomy to address the continued challenge of malnutrition. Existing strategies include local biofortification programs and genetic modification, among other agrarian improvement strategies. Another promising, but rarely discussed pathway is a nutrition-sensitive circular bioeconomy intervention that creates a closed loop system for upcycling biowaste for nutrition-based interventions. This can be pursued in various ways, including exploring the applicability of biowastes as primary ingredients for food or feed production; using biowastes as second-generation nutrient-dense substrates for producing sustainable and nutritious food or feed products and ingredients; and transforming biowastes into sustainable farm inputs such as biofertilizers, biopesticides, or organic composts for improving sustainable agricultural production. The wide availability of bioresources and underutilized biomass across Africa can provide the basis for a nutrition-based circular bioeconomy that confers benefits in both nutrition security and planetary health (Sekabira et al. 2022).

Pursuing a nutrition-sensitive circular bioeconomy can be pivotal for a transformative African food systems agenda that addresses the region's significant malnutrition and food insecurity challenges. This concept can be adopted as a timely and strategic waste management approach that integrates agrifood system development with food security and nutritional outcomes.

Nutrition-oriented or -sensitive initiatives are not new to Africa (Hodge et al. 2015; McLachlan and Landman 2013). However, incorporating circular thinking into these initiatives is a quite novel approach and has potential to thrive, given the practical need and the promising impacts of nutrition-sensitive initiatives in enhancing dietary diversity and household food security in countries such as Ethiopia, Ghana, Kenya, South Africa, Tanzania, and Uganda (Chesoli et al. 2024; Gillespie et al. 2015; Santoso et al. 2021). Nonetheless, like other initiatives, success will depend on creating an enabling environment.

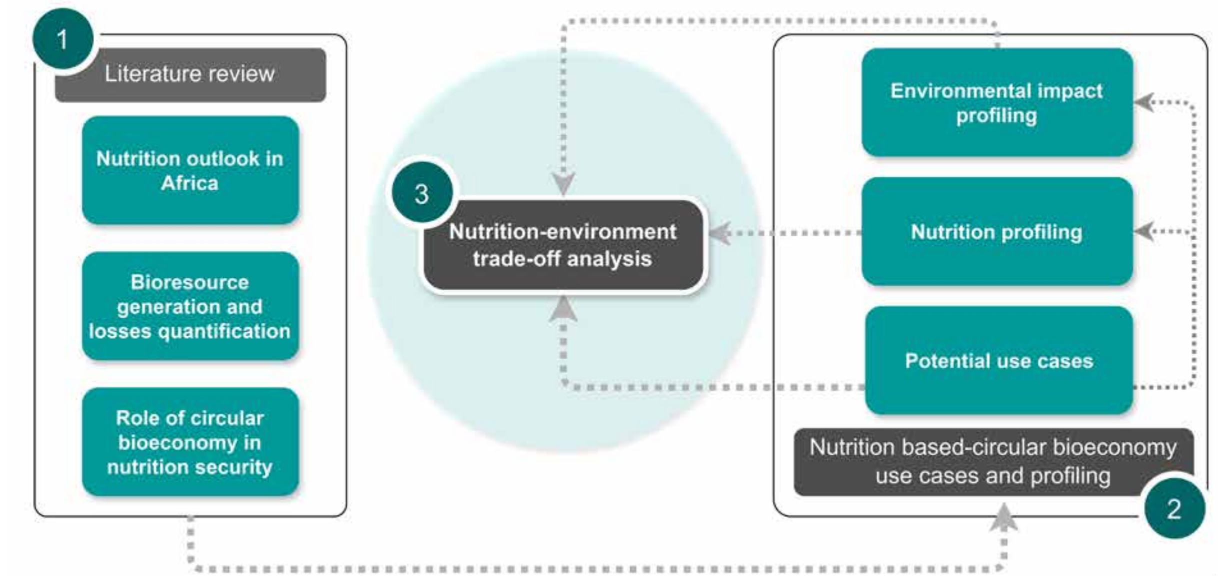
Recent research highlights various strategies within the bioeconomy framework, including the development of bioeconomic models that focus on the production, transformation, and trade of biological goods (Callo-Concha et al. 2020a, 2020b). These models emphasize creating value webs that connect different sectors of the economy, thereby fostering synergies that can lead to improved bioeconomy for promoting food and nutrition security. Subsequent actions should enable a network for creating nutritional value and positive socio-economic outcomes from biowaste. This strategy will facilitate the realization of the potential benefits of a nutrition-sensitive circular bioeconomy.

This chapter explores the potential of a nutrition-sensitive circular bioeconomy in transforming Africa's food systems, examining both the challenges and opportunities that lie ahead. This lens provides a better understanding of how to harness bioeconomic principles to achieve sustainable development goals, ensuring that food systems not only support economic growth but also advance health and environmental objectives across the continent.

Conceptual Framework

This chapter is structured in three key sections. The first section reviews nutrition challenges in Africa, emphasizing the double burden of malnutrition and highlighting the associated consequences. The section ends with an overview of some existing nutrition interventions in response to the prevailing challenges. It provides the basis for the second section to examine the role of circular bioeconomy in addressing the identified nutrition challenges. The application of circular bioeconomy in edible mushrooms, edible insects, and edible fiber production is discussed and linked with an analysis of Africa's bioresource generation and losses to identify current potential for a circular bioeconomy. Following this, the third section explores potential local cases in which Africa's variety of generated biowastes could be used as primary substrates for nutrition-based circular bioeconomy interventions. These use cases are then profiled for their nutritional and environmental impact performance, based on literature data scraping and analysis. Finally, the chapter illustrates the environmental–nutrition–sustainability trade-offs associated with the potential use cases to help identify "sweet spots" and challenges for embracing local nutrition-based circular interventions in Africa's bioeconomy revolution. Figure 8.1 summarizes the conceptual framework of this chapter.

FIGURE 8.1—FLOW OF STUDY



Source: Authors.

Overview of Nutrition Challenges in Africa

Malnutrition remains one of the most important challenges in both advanced regions and developing countries. It occurs either in the form of overnutrition or undernutrition, with the general perception that overnutrition is prevalent in advanced or urban regions while undernutrition occurs mostly in developing or rural regions (Guldan 2020). In developed countries, obesity, a form of malnutrition, has escalated, affecting more than 30 percent of adults and leading to increased healthcare costs and reduced productivity (Kohutek, Homolova, and Bystricky 2024). Conversely, developing nations face high rates of undernutrition, with more than 1 billion people suffering from micronutrient deficiencies, known as hidden hunger (Dessie et al. 2024). This issue contributes to stunted growth, weakened immunity, and increased mortality rates, particularly among children. In Africa, malnutrition has been prominent among food system challenges, driven by complex and interconnected economic factors including rapid population growth, urbanization, poverty, inefficient food supply chains and corresponding infrastructural inadequacy, marginal intervention strategies, climate change, and other geopolitical instabilities (Adeyeye et al. 2017; Gooding et al. 2024; Seifu et al. 2024; Shipanga, Kappas, and Wyss 2024). These factors have worsened the regional malnutrition crisis, significantly increasing undernourishment among vulnerable groups, including children and the elderly (Okyere et al. 2024; Us, Sembiring, and Safitri 2024), and food availability projections show that the existing malnutrition challenges in Africa are likely to remain unchanged unless radical food system policies are implemented rapidly (Abe-Inge and Kwofie 2023). This section explores the main challenges and implications of the double burden of malnutrition across the continent.

Overnutrition Burden

The impacts of overnutrition on health include overweight, obesity, and associated noncommunicable diseases. As mentioned earlier, overnutrition has previously been deemed a major concern in the advanced or urban regions of the world, and thus may be expected to be of lesser concern in less developed or poorer regions. However, a recent World Health Organization (WHO) study (2022) revealed that 24 percent of African children under age five are overweight. The analysis showed that by 2023, obesity prevalence among adults in 10 high-burden African countries could range from 13.6 percent to 31 percent, and among children and adolescents from 5 percent to 16.5 percent (WHO Africa 2022). Countries with the highest burdens include Algeria, Eswatini, Gabon, Kenya, Libya, Mauritius, South Africa, Tanzania, Uganda, and Zimbabwe (SciDev.net 2022). Rising obesity rates are seen as a growing problem requiring an urgent strategy. Data retrieved from the WHO Global Health Observatory (2024), as summarized in Table 8.1, show a high prevalence of overweight among African adults, indicating the potential increase in obesity prevalence in Africa. The data further show the share of adults (ages 18 years and older) who are overweight is highest (60–67 percent) in North Africa and lowest (22 percent) in Niger, Eritrea, Burundi, and Uganda.

Nutrition-related overweight is linked to high consumption of calorie-dense foods such as roots, tubers, cereals, grains, fats, oils, and sugar. A study by Abe-Inge and Kwofie (2023) reported that Africa's food supply is largely dominated by starchy staples, especially in North Africa. The findings further indicated that the apparent consumption rate (566–816 grams per capita per day) of starchy staples among Africans exceeds the average recommended intake (282 g/capita/day) recommended by the EAT–Lancet diet (Willett et al. 2019). Similarly, the same study revealed an average excess consumption of sugar, alcohol, fats, and oils. In addition, there is growing prevalence, convenience, and availability of ultra-processed foods and the supermarkets where they are usually purchased. These excessive consumption rates coupled with more sedentary lifestyles signal the need for healthier and nutrition-sensitive food systems.

Undernutrition Burden

Despite ongoing interventions, undernutrition remains critically high in Africa, even as overnutrition rates are rising. This double burden of malnutrition in Africa is highlighted in the study by Mbogori and colleagues (2020), which showed that African countries with high GDP had the highest rates of overnutrition impacts, while low GDP countries recorded high rates of undernutrition.

TABLE 8.1—AGE-STANDARDIZED SHARE OF ADULTS WHO ARE OVERWEIGHT IN AFRICA

Country	Shares (%)	Country	Shares (%)
Libya	66.8	Benin	29.5
Egypt	63.5	Nigeria	28.9
Algeria	62.0	Sudan (former)	28.9
Tunisia	61.6	Senegal	28.4
Morocco	60.4	Somalia	28.4
South Africa	53.8	Mali	28.1
Yemen	48.8	Togo	28.1
Botswana	43.4	Zambia	27.8
Namibia	40.6	Sierra Leone	27.7
Gabon	40.2	Tanzania	27.7
Lesotho	38.7	Angola	27.5
Djibouti	38.6	Comoros	27.1
Eswatini	38.4	Equatorial Guinea	26.7
Zimbabwe	38.2	Guinea	26.6
Seychelles	36.8	Mozambique	26.4
Sao Tome and Principe	35.4	Central African Republic	26.2
Cabo Verde	34.8	Kenya	25.5
Mauritania	34.4	DR Congo	25.3
Cameroon	33.6	Rwanda	25.1
Mauritius	32.3	Madagascar	23.9
Ghana	32.0	Malawi	23.4
Gambia	31.9	Burkina Faso	23.2
Côte d'Ivoire	31.6	Chad	23.1
Africa (WHO)	31.1	Uganda	22.4
Rep. of Congo	30.9	Burundi	22.2
Liberia	30.9	Eritrea	22.0
Guinea-Bissau	29.9	Niger	22.0

Source: Adapted from WHO Global Health Observatory (2024).
Note: WHO = World Health Organization.

Undernutrition occurs when there is an inadequate intake of nutrients, leading to nutrient deficiencies and their related diseases. The 2023 Global Hunger Index report showed that the share of undernourished individuals across the world rose from 7.5 percent in 2017 to 9.2 percent in 2022 due to the combined effects of COVID-19, the Russia-Ukraine war, climate change, prolonged political unrest, and economic stagnation (Global Hunger Index 2023). Deficiencies in protein, carbohydrates, and fats are termed *macronutrient deficiencies*, while deficiencies in vitamins and minerals are known as *hidden hunger* or *micronutrient deficiencies*. Hidden hunger can occur without deficits in energy intake (Lowe 2021). Details of the undernutrition burden of Africa are provided in the subsections that follow.

Micronutrient Deficiency

Micronutrient deficiencies persist in Africa, with high risks for iron, iodine, vitamin A, vitamin D, vitamin B12, zinc, calcium, folate, and selenium deficiencies (Bationo, Savadogo, and Goubgou 2022; Gebremedhin 2021; Theuri and Wachira 2022; Joy et al. 2014). The most common and prevalent is iron deficiency, affecting about 70 percent of households in Africa (Christian and Dake 2022).

Micronutrient insufficiency is a major health concern in Africa, particularly in the region south of the Sahara. Over 98 percent of malnourished people worldwide live in developing countries, with African countries south of the Sahara accounting for more than half of these cases (Engidaw et al. 2023; Nxasana et al. 2023). One of the primary factors causing micronutrient deficiency is poor diet. Dietary causes of micronutrient deficiency in Africa include insufficient intake of animal-source foods, fruits, and vegetables due to inadequate availability (Abe-Inge and Kwofie 2023). Animal-source foods, fruits, and vegetables are widely known to be rich sources of several nutrients, including micronutrients. For instance, liver is the richest source of iron, and dairy milk is a great source of calcium and other micronutrients. Hence, the low intake of animal-source foods among Africans could account for the high prevalence of iron deficiency in the region. Mushrooms and edible insects are seemingly less popular yet rich sources of micronutrients such as B vitamins, selenium, copper, vitamin D, and potassium. Their intake among Africans is likely inadequate, although there is no comprehensive publicly available evidence on their supply and consumption rates among Africans. The inadequate intake of micronutrients is associated with neural tube defects, osteoporosis, impaired cognitive function, impaired immune function, cardiovascular diseases, and certain types of cancer (Fulgoni III and Agarwal 2021). It is therefore necessary to consider more strategies and pathways to ensure the adequacy of micronutrient supply to Africans through dietary interventions.

Aside from poor diet, factors such as disease conditions, agronomic factors, restricted access to healthcare, and low literacy levels all contribute to the prevailing micronutrient deficiency in the region (Ohanenye et al. 2021). Research undertaken in South Africa shows a high frequency of micronutrient deficiencies—particularly zinc, iron, and folate—among HIV-infected people with unsuppressed viral loads (Kihara et al. 2020). Moreover, agronomic studies in Africa south of the Sahara show widespread micronutrient inadequacy in arable soils, with zinc being the most inadequate, highlighting the need for strategic interventions to address micronutrient deficiency in Africa (Githanga 2019).

Macronutrient Deficiency

Macronutrient deficiency results from inadequate intake of proteins, carbohydrates, lipids, or a combination of these. In instances where deficiency involves all macronutrients, the terms *protein-energy malnutrition* or *protein-energy undernutrition* are applied. The repercussions of macronutrient deficiency range from mild to life-threatening depending on the type of nutrient, degree of deficiency, health status, and cooccurrence of other deficiencies (Espinosa-Salas and Gonzalez-Arias 2023).

Among the different macronutrient deficiencies in Africa, protein deficiency is the most common (Abe-Inge and Kwofie 2023). Research shows that protein intake in Africa is inadequate. For instance, protein intake among Africans was estimated to be around 30 g/capita/day (Schönfeldt and Gibson Hall 2012), and a recent report indicated the availability of animal-source foods (81–258 g/capita/day), which remain the source of high-quality proteins for Africans (with the exception of southern Africa), is lower than the daily intake of animal-source foods recommended by the EAT–Lancet and African-based dietary guidelines (Abe-Inge and Kwofie 2023). The inadequate intake of quality protein could also be linked to the inadequate availability of legumes, seeds, nuts, and animal-source foods in all regions of the continent other than North Africa (Abe-Inge and Kwofie 2023).

Protein deficiency contributes significantly to the prevailing health and economic burdens of Africa and can take a significant toll on the health, growth, and development of an individual. Health burdens include stunting, muscle wasting, edema, anemia, loss of bone mass, impaired nutrient absorption, immunodeficiency, intrauterine growth restriction, cardiovascular dysfunction, hypoalbuminemia, skin atrophy, and impaired hormone production, particularly of growth and thyroid hormones and insulin (Espinosa-Salas and Gonzalez-Arias 2023; Wu 2016). Although protein intake is generally low and of poor quality in Africa, instances of excessive consumption could be equally economically burdensome due to associated risks of renal, digestive, and vascular abnormalities. Unlike protein, lipid and carbohydrate deficiencies are not common. While both are used in the production of energy in daily activities and metabolic functions of the body, essential fatty acids (part of lipids) play a more essential role in brain and retina development, especially during pregnancy and early life stages (Huffman et al. 2011). Data on the prevalence of essential fatty acid deficiencies in Africa are limited. However, populations that consume low amounts of seeds and animal-source foods are likely to be deficient in essential fatty acids. Research confirms that populations in Africa have an inadequate supply of seeds and animal-source foods to support the required daily intake levels (Abe-Inge and Kwofie 2023, Huffman et al. 2011). The supply of seeds is more inadequate than that of animal-source foods, particularly in Southern Africa, followed by Central Africa, North Africa, East Africa, and then West Africa (Abe-Inge and Kwofie 2023).

Animal food sources of essential fatty acids include meat, seafood, and edible insects such as termites, locusts, crickets, flies, worms, and larvae (Kolobe et al. 2023; Parker et al. 2017). Edible insect consumption has long existed and is noticeable in several African countries such as Angola, Botswana, Burkina Faso, Cameroon, Democratic Republic of Congo (DR Congo), Ghana, Guinea, Kenya, Madagascar, Malawi, Namibia, Nigeria, Rwanda, South Africa, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe (Matandirotya et al. 2022). Due to a lack of data, it is not evident how much insect consumption has contributed to combating fatty acid deficiency in these countries. However, its existence in the region signals the need to adequately integrate its production in African food systems to achieve food and nutrition security.

Existing Interventions and Their Limitations

Overall, the African region south of the Sahara is said to be more affected by malnutrition generally due to the simultaneous presence of persistent poverty (Delisle, Faber, and Revault 2021). As of 2023, out of the 48 African nations south of the Sahara, 22 were low-income countries and 19 were lower-middle-income (Hamadeh, Rompaey, and Metreau 2023), confirming the magnitude of the poverty burden in Africa.

Consequently, several interventions have been made, stemming from the United Nations' Sustainable Development Goals (SDGs) 2 and 3. SDG2 aims to achieve zero hunger with a focus on food security and sustainable agriculture, and SDG3 aims to achieve healthy living and enhanced well-being across all ages. Under these goals, three main strategies are currently employed: biofortification, education, and economic empowerment. Efforts to combat food and nutrition insecurity in Africa have been diverse, encompassing a range of community-level and national initiatives. Despite significant investments, these interventions often face critical limitations that hinder their effectiveness.

Research has shown that current food availability is insufficient to support healthy and adequate daily nutrition among Africans (Abe-Inge and Kwofie 2023). This observation implies that educating consumers on healthy eating and designing food-based dietary guidelines and food guides are not enough to achieve SDG2 and SDG3 in Africa. Extra efforts are required to maximize the efficiency of nutritious food production and reduce food losses and waste. Biofortification programs, on the other hand, face barriers such as low accessibility and adoption by farmers (AU 2023), consumers' skepticism about health impacts, and significant nutrient losses during cooking at the household level (Eyinla et al. 2019). These challenges are reinforced by the inherent general difficulty of behavioral change.

Furthermore, many interventions are not sustainable due to limited funding, poor policy integration, and insufficient government backing, which limit their scalability and impact on larger regional or national food security concerns. Furthermore, social and cultural issues such as resistance to changing conventional eating patterns can impede successful acceptance of suggested nutritional practices and are not sufficiently considered in program design.

Role of Circular Bioeconomy in Addressing Nutrition Challenges

Africa's shift toward a bioeconomy for sustainable food systems transformation has recently embraced the circular bioeconomy. This approach addresses regional challenges such as unsustainable agricultural practices, waste generation, food and nutrition insecurity, and climate change (D'Amato, Veijonaho, and Toppinen 2020; Feleke et al. 2021; Sekabira et al. 2022). Thus, its adoption supports the regional quest for achieving an economically resilient, environmentally favorable, and socially equitable economy (D'Amato and Korhonen 2021; D'Amato, Veijonaho, and Toppinen 2020).

For example, converting biowaste to vermicompost, biofertilizers, and biopesticides can reduce the costs and environmental burdens of synthetic chemicals while improving agricultural productivity and food availability. Similarly, by exploring the vast potential of agricultural and agro-industrial biowaste for nutrient-dense bioingredients, biofoods, and feed, a circular bioeconomy could be structured as a vehicle for accelerating strides toward meeting food and nutrition security. These possibilities have been observed in some African regions, with institutions such as the International Institute of Tropical Agriculture, International Centre of Insect Physiology and Ecology, and the Africa Circular Economy Alliance implementing advocacy and programmatic actions to explore the possible interactions between circular bioeconomy, food and nutrition security, and climate adaptation (Sekabira et al. 2022).

Currently, Africa's circular bioeconomy trend prominently captures low-value composting, animal feed, and bioenergy pathways, leaving the nutrition-oriented possibilities barely explored. A nutrition-based circular bioeconomy would offer Africa a chance to bridge gaps in nutrition, health, and environmental sustainability while creating value and wealth from waste and underused byproducts. Recent advances in this direction are seen in research and microenterprise exploration of some potential waste-to-product circularity pathways including the transformation of waste into food products such as dietary fiber, juices, powders, and jams (Abasubong et al. 2023; Aidoo, Kwofie, and Ngadi 2022); cultivation of edible mushroom and insects for food and feed (Madau et al. 2020; Nyakeri et al. 2017; Tanga et al. 2021); and second-generation microbial protein, biopesticides (Akutse et al. 2020; Ashaolu et al. 2021; Kusumaningtyas et al. 2020), and biofertilizers, especially in the eastern and western corridors (Sekabira et al. 2022). For instance, a Ghanaian start-up converts spent mango and pineapple pulp from juice extraction into edible dietary fiber products (Pneuma Food Scientifics 2023), thus exemplifying a practical application of circular bioeconomy to create value-added products and achieve nutrition security.

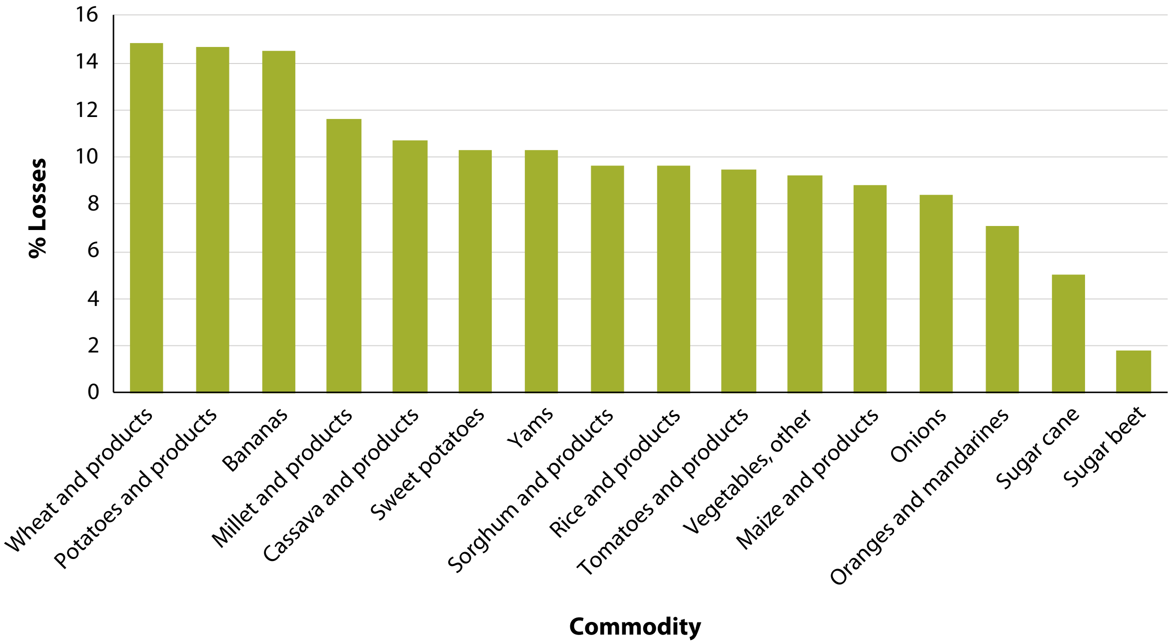
Focusing on Ghana, researchers explored the practical applications of the circular bioeconomy framework, particularly through the multiple R approach (reduce, reuse, refuse, rethink, repair, recycle) in agriculture (Boon and Anuga 2020). Their findings suggest that the circular bioeconomy can lead to more efficient resource use, increased agricultural yields, and improvements in the quality of agricultural products, which in turn enhance food and nutrition security. However, the successful application of these principles requires overcoming significant technological and investment challenges, as well as fostering a greater understanding of the economic, social, and environmental impacts of such transitions.

The lack of supportive scientific evidence has been one of Africa's primary barriers to a widespread circular bioeconomy adoption, given uncertainties related to the sustainability trade-offs of associated pathways (Sekabira et al. 2022). Thus, following the proposed nutrition-based circular bioeconomy path would require development of concrete scientific evidence that delineates the possible trade-offs of the paradigm and associated pathways and helps to frame sustainable solutions. The next section of this chapter provides a preliminary exploration of such trade-offs for some potential nutrition-based circular bioeconomy use cases.

Mapping Out Agrifood Waste and Use in Africa

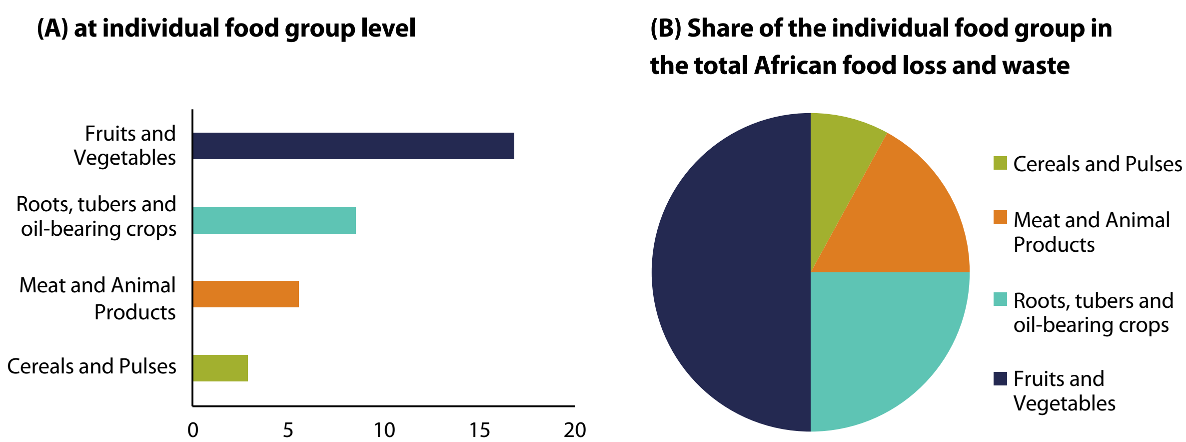
Agrifood waste includes the edible and inedible fractions of food removed from the human food supply chain. It remains a challenging problem in Africa due to the region's tropical weather, as high temperatures promote rapid deterioration of horticultural produce at all the stages of the food supply and value chain. In addition to conditions that favor food spoilage and waste, there is limited technological capacity to use these generated wastes. Although there are limited data on the rates of food waste and loss in Africa, this chapter uses food loss data from the FAOSTAT Food Balance Sheets to represent the continent's agrifood waste levels. As presented in Figure 8.2, the food waste rates in 2021 (the most recent FAOSTAT data available) are highest for wheat, potatoes, and bananas, with sugar beets being the least wasted. In addition, Figure 8.3 demonstrates that food waste rates are highest for fruits and vegetables. By food group (Figure 8.3A), fruits and vegetables showed about 17 percent average waste across Africa between 2000 and 2022. Cereals and pulses were the food group with the least food loss

FIGURE 8.2—PERCENTAGE LOSSES FROM TOP PRODUCED COMMODITIES IN AFRICA



Source: FAOSTATS Food Balance Sheets

FIGURE 8.3—AVERAGE AFRICAN FOOD WASTE AND LOSS RATE AS A PERCENTAGE OF DOMESTIC PRODUCTION FROM 2000 TO 2022



Source: Authors, calculated from FAO (2024).

and waste (8 percent) recorded within the same period. Figure 8.3B further demonstrates clearly that fruits and vegetables account for about 50 percent of the total food lost and wasted in Africa .

Among the top 10 African countries in terms of food loss and waste, Tanzania leads with 152 kg/capita/year of household waste (medium confidence estimate) (FAO 2024; Oluwole 2024). The remaining countries in the top 10 list are Uganda, Seychelles, Rwanda, Nigeria, Mozambique, Madagascar, Niger, Burkina Faso, and Mali, while the country with the lowest food waste rate (48 kg/capita/year) is Zimbabwe (UNEP 2024). Due to aggregation of data, it is not sufficiently clear which individual food commodities and/or stages of the supply and value chain present the highest waste in these countries. In addition, little is reported about the nature of waste generated, such as the proportions that are liquid or solid.

Regardless, it has been estimated from the available data that the majority (60 percent) of agrifood waste in 2022 occurred at the household level (UNEP 2024). Meanwhile, among smallholder farmers who dominate the African agricultural industry, food waste and loss rates are often highest at the farm level due to a lack of timely access to markets, poor road networks, and inadequate preservation and storage techniques, especially for perishable produce. However, information is limited regarding the edible and inedible portions of the generated food waste and their proportions, use rates, and use efficiency. However, researchers have noted that a staggering 90 percent of agrifood waste often ends up in landfills, with the remaining 10 percent is used for either fertilizer or animal feed (Bessa, Agonga, and Monthe 2021).

While there are numerous opportunities for integrating agrifood waste into the circular bioeconomy (as highlighted in subsequent sections of this chapter), there are also significant challenges. These include the need for better policy frameworks, more robust technological solutions for waste processing, and greater public awareness and acceptance of products derived from biowaste. The success of these initiatives also depends on overcoming logistical and economic barriers to ensure that the derived products are safe, economically viable, and socially acceptable (Mak et al. 2020).

Use Cases: Nutrition and Environmental Impact Profiling of Nutrition-Sensitive Circular Bioeconomy Pathways

Following the discussion in the previous section, this section profiles the sustainability performance of some nutrition-based circular bioeconomy interventions. The section begins with an overview of some potential use cases and their advantages and ends with an environmental impact and nutrition profiling based on literature.

Potential Use Cases

Circular Edible Mushroom Production

The unique culinary, nutritional, and nutraceutical benefits of mushrooms for food, feed, and medicinal use have stimulated global demand. This increased demand brought market value of these products to about US$68 billion in 2023, more than double the value in the past decade. With demand still rising, their market value is projected to double again to about US$136 billion in the next decade, with expected market growth in Europe, Asia Pacific, Latin America, and African countries such as South Africa and Nigeria. The rapid rise in global adoption, coupled with threats of extinction of wild edible mushrooms and the desire for more controlled cultivation, has stimulated domesticated edible mushroom farming, which now represents 54 percent of the current global market. The remaining 46 percent is classified under medicinal (38 percent) and wild mushroom (8 percent) production (Dimopoulou et al. 2022).

Domesticated edible mushroom farming has adopted and used agro-industrial food waste materials such as banana leaves, empty oil palm inflorescence, rice straw waste, maize stubble, bagasse, cotton waste, pineapple leaves, cassava peels, and sugarcane as substrates (Kortei, Dzogbefia, and Obodai 2014; Kumla et al. 2020; Munir et al. 2023). Thus, mushroom farming presents an easily adoptable opportunity to implement a nutrition-sensitive circular bioeconomy in Africa for food and nutrition while sustainably converting wastes into organic fertilizer for sustainable food crop production.

A chemical profiling of several edible mushrooms, including *Agaricus bisporus*, *Agaricus blazei*, *Amanita caesarea*, *Boletus aereus*, *Boletus edulis*, *Cantharellus cibarius*, *Coprinus comatus*, *Cordyceps militaris*, *Craterellus cornucopioides*, *Craterellus lutescens*, *Ganoderma lucidum*, *Grifola frondosa*, *Hericium erinaceus*, *Lentinula edodes*, *Marasmius oreades*, *Morchella esculenta*, and *Pleurotus ostreatus*, showed significant composition of proteins (13.8–38.5 grams per 100 grams), carbohydrates (32.0–61.4 g/100 g), fats (0.4-5.9 g/100 g), and other vital micronutrients and phytochemicals (Dimopoulou et al. 2022). For most species, a serving size of 100 grams could contribute about 15–30 percent of the recommended daily intake of most vitamins, especially vitamin B complex, and microelements including potassium, phosphorus, iron, zinc (high in most species), magnesium, and copper (Dimopoulou et al. 2022; Gargano et al. 2020; Vetter 2019). This indicates an opportunity to explore the use of mushrooms in micro- and macronutrient deficiency interventions. Already, the strategy is being pushed as a programmatic action in several global contexts, including Algeria, Morocco, Nigeria, Tunisia, and other Central and Southern African countries. There is also growing advocacy concerning the inclusion of edible mushrooms in flexitarian diets as substitutes for animal meat (Das et al. 2021; Valverde, Hernandez-Perez, and Paredes-Lopez 2015). Against this background, the change in the agricultural paradigm toward a restorative culture has augmented concerns about possible sustainability risks, triggering stakeholder actions to streamline local farming practices to attain a balance between sustainability and nutrition security benefits. These efforts have heightened the popularity of circularizing local agricultural and agro-industrial biowastes in domesticated farming, especially in African countries south of the Sahara such as DR Congo (Mpadi and Bangala 2020), Egypt (Yehia 2012), Ethiopia (Gashaw and Getu 2020), and Tanzania (Magingo et al. 2004), where biowastes are used as a nutrient supplement, spawn substrate, or growth substrate (Ekun et al. 2021). In addition, recent literature has outlined several pathways to design for and optimize eco-friendliness (Gashaw and Getu 2020, Magingo et al. 2004; Mlambo and Maphosa 2022; Mpadi and Bangala 2020). Notably, such cultivation techniques could be a cost-efficient and lucrative option for delivering the nutritional value of edible mushrooms while conferring the benefits of carbon emission reduction gained through high-value upcycling of organic waste.

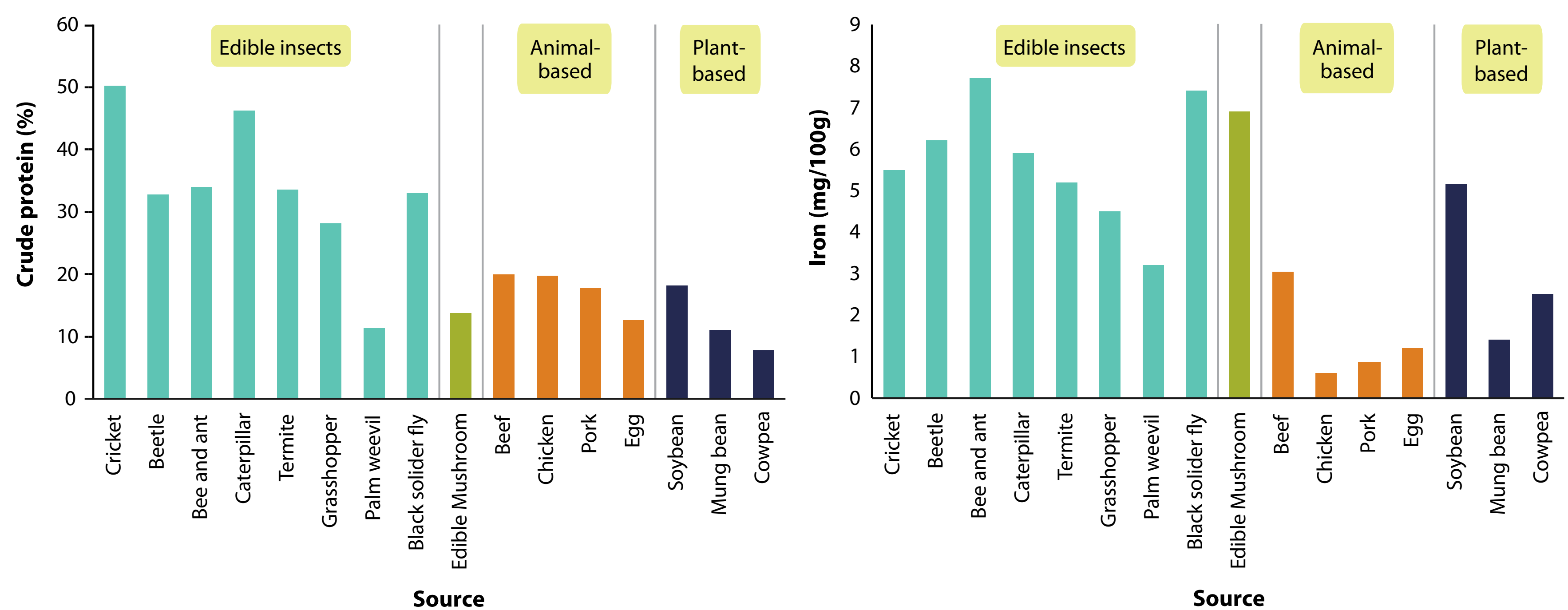
Despite recent progress in circular edible mushroom production in Africa, the overall regional adoption rates are very low. This signals an opportunity for Africa to maximize interest in embracing this nutrition-oriented circular bioeconomy approach for sustainable food systems transformation. In this chapter, a system scenario developed by Ekun and colleagues (2021) is considered and explored as a use case to ascertain the environmental–nutrition co-benefits of circular edible mushroom production.

Use of Biowaste for Conventional and Alternative Proteins Production

The exploration of alternative proteins such as edible insects and microbial proteins for the sustainable and healthy satisfaction of burgeoning consumer protein needs has gained substantial traction. In Africa, interest has been stronger in edible insects, which are becoming prominent because of their ability to grow on wide streams of substrates and potential to advance a sustainable protein supply (Wade and Hoelle 2020). There are roughly 2,000 insect species that can be used for food, 25 percent of which are consumed in Africa (Kelemu et al. 2015). Edible insect farming requires relatively less land, water, and feed compared to conventional meat production and is attractive for its high nutritional value and carbon-saving potential.

Previous studies have compared the nutritional profile of edible insects with prominent meat products, reporting greater potential for edible insects. For instance, a comparison of 100 grams of mealworm larvae and of beef showed about 25 grams and 20 grams of protein, respectively (Liceaga 2021). Likewise, the protein contents of other edible insects cultivated on varying organic wastes have been compared with several meat alternatives, also reflecting relatively greater potential, as shown in Figure 8.4 (Tanga et al. 2021). However, there is a limited uptake of black soldier flies directly as human food due to safety concerns

FIGURE 8.4—COMPARISON OF CRUDE PROTEIN (LEFT GRAPH) AND IRON (RIGHT GRAPH) CONTENTS OF EDIBLE INSECTS WITH CONVENTIONAL PLANT- AND ANIMAL-BASED FOODS

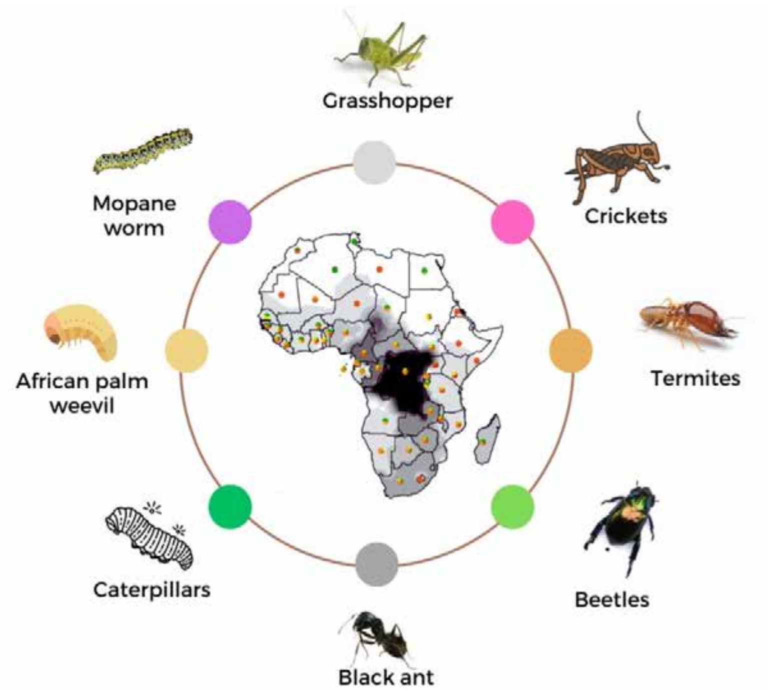


Source: Tanga et al. (2021).

and other consumer misconceptions (Tanga et al. 2021). The common practice is to leverage them as conventional meal substitutes in aquacultural production, which in turn increases productivity and availability of sustainable protein food to meet local protein needs (Nyakeri et al. 2017).

Insects also have a high feed-conversion ratio when compared to livestock and poultry, saving significant economic and environmental costs associated with feed production and processing. In terms of resource demand, Pells (2023) mentioned that cricket production requires less land use than meat production, with offsets of up to sixfold for cattle, fourfold for sheep, and 50 percent for pigs and chickens, emphasizing the potential of edible insect farming in minimizing forest land clearing and degradation. The global market for edible insects is booming, expected to grow at a whopping 47 percent compound annual growth rate between 2023 and 2032, up from a market value of about US$1.2 billion (Global Market Insights 2022).

FIGURE 8.5—PROMINENT INSECTS MOSTLY CONSUMED IN AFRICA



Source: Adapted from Awobusuyi, Siwela, and Pillay (2021); Chakravarthy et al. (2016); Grabowski et al. (2020); Hlongwane, Slotow, and Munyai (2021); and Niassy and Ekesi (2017).

Note: Gray shading indicates the intensity of insect farming.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

Africa has contributed comparatively little to this market growth despite the availability of a wide market niche, a strong tradition of insect consumption, and rich diversity of edible insects, which signal an opportunity to leverage local capacities to drive local innovations. Cameroon, Central African Republic, DR Congo, Nigeria, Republic of Congo, South Africa, Uganda, Zambia, and Zimbabwe are the predominant insect-eating countries in Africa (Niassy and Ekesi 2017). Some of the commonly consumed edible insects in Africa are shown in Figure 8.5.

Among the most commonly cultivated insects in Africa are the black soldier fly, followed by crickets, beetles, and palm weevil larvae. Although mealworms, which are probably the most commercialized edible insect, are currently not largely consumed in Africa, the use of available food waste generated in Africa can be explored in its production and consumption in the region.

Table 8.2 shows examples of food waste that have been used or have demonstrated potential as feed materials in insect production for both human food and animal feed. Fruit and vegetable waste, which accounts for the largest share of Africa's food waste output, has shown applicability in the cultivation of black soldier fly (Dzepe et al. 2023; Ganvir et al. 2022), mealworm (Zhang et al. 2019), and Cambodian cricket (Miech et al. 2016). Waste from roots/tubers and cereals/grains are being used for mealworm (Zhang et al. 2019), figeater beetle (Slagle and Davidowitz 2022), and Cambodian cricket (Miech et al. 2016) farming. Palm weevil larvae farming relies on palm yolk sourced from a felled palm tree during the tapping of palm wine (Elemo et al. 2011). This technique of palm weevil larvae cultivation is unsustainable, emphasizing the need to explore sustainable alternative techniques that use household food waste. Africa has an enormous accumulation of more than 125 million metric tons of organic waste annually. Less than 5 percent of this waste is effectively recycled (Linda et al. 2019).

TABLE 8.2—SELECTED FARMED INSECTS' APPLICATION AND FEED MATERIALS

Insect Name	Application	Feed Materials	Reference
Black soldier fly	Human food and animal feed	Fruit peels (summer fruits, papaya, and banana), vegetables, bakery waste, cocoa pods, and kitchen waste	(Dzepe et al. 2023; Ganvir et al. 2022)
Figeater beetle	Human food and animal feed	Dairy cow manure, spent mushroom substrate, spent brewer's grain, and leaves	(Slagle and Davidowitz 2022)
Mealworm	Human food and animal feed	Mushroom spent corn stover, highly denatured soybean meal, watermelon rinds, banana peels, and spirit distillers' grains	(Zhang et al. 2019)
House cricket	Human food and animal feed	Grocery store food waste after aerobic enzymatic digestion, and municipal food waste heterogeneous substrate	(Lundy and Parrella 2015)
Housefly	Animal and fish feed	Mixture of egg content, hatchery waste, and wheat bran	(Makkar et al. 2014)
Cambodian cricket	Human and animal feed	Rice bran, cassava plant tops, water spinach, spent grain, and residues from mung bean sprout production	(Miech et al. 2016)
Palm weevil larvae	Human food	Palm yolk	(Elemo et al. 2011)

Use of Biowaste for Functional Extract and Platform Chemical Production

Functional extracts are natural compounds typically derived from plants and other agricultural sources, which can be added to food products to render certain health or other functional benefits (Lamponi 2021). Platform chemicals are basic chemical building blocks used to produce different kinds of fine and specialty chemicals (Pachapur, Sarma, Brar, and Chaabouni 2016). Africa has great potential to expand the functional extract and platform chemical market for satisfying local needs by leveraging local circular bioeconomy opportunities. Considering the diverse chemical densities of the variety of biowastes broadly reported in the literature, it would be possible to replace a significant portion of the synthetic functional ingredient and platform chemical market with bio-based alternatives to meet local sustainability targets. A typical example for functional extract production is the case of cashew apples, which is a rich source of dietary fiber, potassium, and vitamin C (about 5 and 10 times that of citrus fruits and pineapples, respectively), highlighting opportunities for producing functional products rich in fiber, potassium, and vitamin C (Akyereko et al. 2023). However, aside from the minute portions either consumed in their raw state or processed at small scales into juice and wine, the vast majority of cashew apples produced in Africa, and globally, faces gross underutilization (Das and Arora 2017; Sobhana 2019; Sobhana et al. 2015). Currently, about 80–90 percent of cashew apples produced globally are discarded (Dimoso et al. 2020). Statistics show that Africa produces about 60 percent of the world's cashews, dominated by Côte d'Ivoire, Nigeria, and Tanzania (Jeyavishnu et al. 2021). Thus, assuming Africa contributes 50 percent of the reported 35 million tons of annual cashew apple waste biomass, simple arithmetic likens that to dumping 600,000 standard 40-foot shipping cargo containers with a carrying capacity of 27 metric tons. There is, therefore, a huge opportunity to restructure the value chain in growing regions to embrace the underexplored commercial potential of cashew apple biomass. As mentioned earlier, this could be a viable circular business model for bridging gaps in dietary fiber and vitamin C supply through cashew apple powder and juice production, providing new frontiers in job and incentive stream creation that could empower women and support gender parity within the value chain. Similarly, waste biomass can be explored for platform organic acid or alcohol platform chemicals through biotechnological approaches, considering its high sugar content. The African chemical industry is generally considered an emerging one, and the region relies mainly on imports to satisfy local demand. Thus, the proposed cashew apple–to–platform chemical production pathway could be one of many opportunities to localize production and supply, considering that the continent is poised to sustainably advance the local chemical industry and strengthen intracontinental trade. This could be facilitated by strengthening local small and medium enterprises to spearhead the development of the industry, supported by the necessary financial support. The same can be said for other nutrient-dense waste biomass with such potential for functional nutrient extraction, especially fruit and vegetable wastes that contain a diverse range of useful phytochemicals.

Aquaponics for Fish Protein and Micronutrient-Rich Vegetable Production

Aquaponics is a modern agricultural technique that combines both aquaculture and hydroponics to simultaneously grow fish and plants. In this farming technique, aquaculture is carried out in fish tanks in combination with plants grown in beds. The wastewater generated from fish tanks is fed to the hydroponic system where the plants absorb the nutrients contained in the wastewater inflow, thus acting as biofilters. The aquaponic system can be leveraged to grow fish and vegetables to boost the supply of protein and micronutrients in Africa. The technique could be applied to commonly farmed edible fish such as tilapia, catfish, trout, and nutrient-rich vegetables such as leafy green vegetables, tomatoes, eggplant, and many others (GoGreen Aquaponics 2023). The technique uses less water and no inorganic fertilizers, therefore yielding nutrient-rich foods with little harm to the environment. In addition to its eco-friendly nature, the aquaponics market is growing rapidly, especially in North America and Asia, with an estimated current global market size of US$1.2 billion, forecast to reach US$1.92 billion by 2029 (Mordor Intelligence 2024).

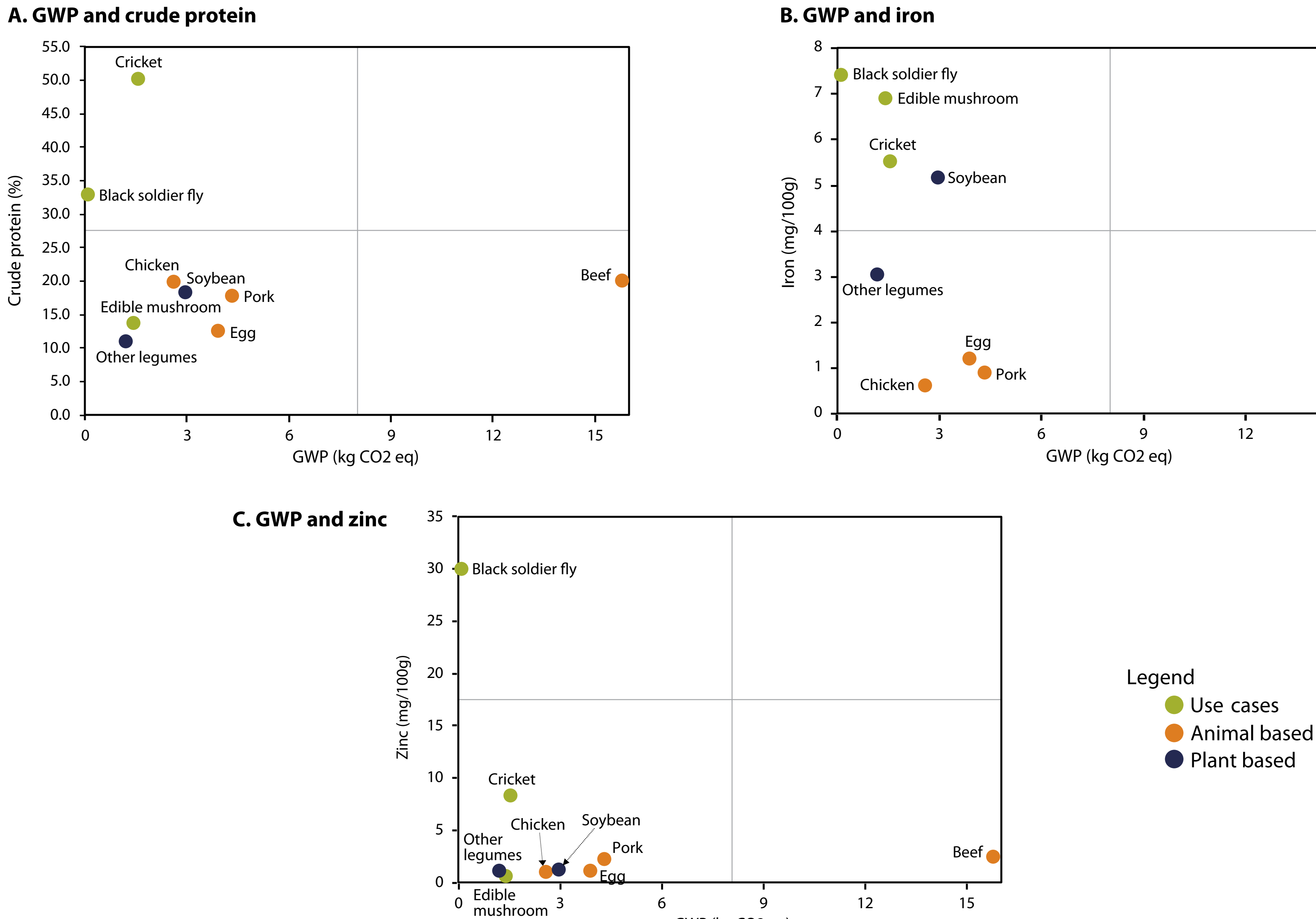
Millions of people in Africa rely on fish as a source of protein, underpinning the rising growth rate of aquaculture and consumption rate in several nations of the region. Notably, the per capita consumption rate increased from 2.8 kilograms in 1961 to 12.2 kilograms in 2010 (Eyayu, Getahun, and Keyombe 2023). In addition, Africa's total annual inland and marine capture fish production grew significantly from 1.47 million tons in the 1980s to 3.21 million tons in 2020 (FAO 2022). In addition to the region's growing population resulting in a higher number of fish consumers, there is a growing European market for African-produced fish (Eyayu, Getahun, and Keyombe 2023; Globefish 2024). The European market constitutes about 70 percent of the African fisheries export market, with Mauritius, Morocco, Namibia, Senegal, and South Africa among the top 50 global exporters (Globefish 2024). This high demand for fish contributes to job opportunities and consequently to the economies of fish-producing nations (Eyayu, Getahun, and Keyombe 2023). These dynamics justify the implementation of modern and sustainable techniques such as aquaponics, which is suitable for leading aquaculture in African countries such as Egypt, Ghana, Kenya, Nigeria, and Uganda (Globefish 2024; Kaleem and Bio Singou Sabi 2021). The technology has already been adopted noticeably across Africa, with Egypt, Ghana, Kenya, and South Africa appearing to be the leading users (Obirikorang et al. 2021). In Ghana, eco-aquaponics—a growing field of aquaponics that exploits the symbiosis between fish and algal production—has been actively promoted by the Bio Green Agro start-up (Okai 2021). In this aquaponic system, algae is grown within the farming pools as primary feed for the fish and later as concentrated fertilizer for crop production application. The system has been inspected and certified by governing bodies such as the Participatory Guarantee System (Ghana) under the auspices of the International Federation of Organic Agricultural Movements (Okai 2021). Similar initiatives are being explored in other African countries such as Nigeria (Okomoda et al. 2022; Benjamin, Tzemi, and Fialho 2021).

While fish and vegetables produced from aquaponics are used as food and nutrient sources for humans, the resulting solid waste from fish and vegetables can be used in insect farming to create both feed for fish farming and protein sources for human consumption. Therefore, aquaponics is a highly promising circular bioeconomy technique with a great potential to contribute to food and nutrition security in Africa, especially in regions with high fish and insect protein consumption.

Nutrition-Based Sustainability Trade-Off Analysis for Food-Based Circularity Pathways

The previous sections of this chapter discussed nutrition challenges in Africa, highlighting the promising potential of a nutrition-based circular bioeconomy as a sustainable pathway for delivering regional nutrition security targets. This section focuses on quantifying the environmental and nutritional profiles of a nutrition-based circular bioeconomy and estimating the potential environmental–nutrition trade-offs with some conventional nutrition sources. The environmental and nutritional profiles are summarized in Tables 9A.1 and 9A.2 of the appendix. Figure 8.6 compares some use cases against some conventional plant- and animal-based protein sources by plotting protein, iron, and zinc profiles and global warming potential. In Figure 8.6a, the use cases of crickets and black soldier flies show a relative advantage in combining protein supply with carbon-zero targets, given their relatively lower global warming potentials and high protein content. Edible mushrooms show similar benefits, but with

FIGURE 8.6—ENVIRONMENTAL-NUTRITION TRADE-OFF ANALYSIS OF USE CASES AGAINST CONVENTIONAL PROTEIN SOURCES: (A) GWP AND CRUDE PROTEIN (B) GWP AND IRON (C) GWP AND ZINC



Source: Authors.

Note: GWP = global warming potential.

less protein content, comparing favorably with other plant- and animal-based proteins while surpassing them in terms of environmental benefits. The same is seen for the micronutrient trade-off analysis (Figure 8.6, panels b and c), where black soldier flies and edible mushrooms surpass conventional nutrient sources in terms of both micronutrient supply and global warming reduction. These trends conform with the existing literature, which positions edible insects and mushrooms as sustainable, high-value nutrient sources for achieving environmental–nutrition co-benefits. It is important to mention that due to data lags, the environmental data for the use cases mainly captured conventional production systems, most of which relied on synthetic substrates. Thus, the visualized benefits may extend even further, considering the claims that organic substrates can offer additional environmental impact offsets (Aidoo et al. 2023, 2024). Therefore, with the analysis indicating that the use cases can achieve greater environmental–nutrition co-benefits, the findings of this study could be used to justify policy or programmatic actions for adopting and expanding these cases as regional nutrition-based circular bioeconomy interventions. The possible environmental impact offsets associated with such implementations are shown in Table 8A.3 of the appendix.

Conclusion and Recommendations

This chapter demonstrates that the circular bioeconomy concept has great potential to enhance Africa's food and nutrient security while also providing environmental benefits. The concept is useful for transforming agrifood waste into nutrients such as protein, dietary fiber, and micronutrients for human consumption.

In regions with high insect consumption, insect farmers should be encouraged to liaise with food producers to use any generated biowaste in their insect farming businesses. While aquaponics should be promoted in countries where fish farming is prevalent, such as Egypt, Ghana, Kenya, Nigeria, and Uganda, it can also be implemented in drought-prone regions of Africa to ensure water conservation and to boost the supply of nutrient-rich vegetables and fish in these regions. In addition, agrifood waste such as fruit waste could be used in the production of edible functional components such as dietary fiber and nutraceuticals useful in the prevention of overnutrition-related noncommunicable diseases.

The circular bioeconomy holds significant promise as a strategy to address the complex challenges of nutrition and sustainability in Africa. By fostering efficient resource use and waste reduction, a circular bioeconomy can contribute to more resilient food systems that support both people and the planet. However, realizing this potential fully will require concerted efforts to overcome existing barriers, particularly in terms of policy, community engagement, and technological innovation. With robust support and a clear understanding of its multifaceted benefits, circular bioeconomy can play a critical role in transforming Africa's food systems for better health and environmental outcomes.

Further research aimed at validating and tackling the potential barriers to scaling up these potential use cases is required. Community-based education and training, behavioral change campaigns, and/or awareness strengthening by agricultural agencies and personnel will then be required to educate all stakeholders along the food value chain about these new production pathways and to trigger consumer demand. Funds from government and funding agencies are necessary to aid producers and individuals in establishing and incorporating circular bioeconomy principles into their current practices. Food processors and entrepreneurs could be targeted in establishing startup businesses that incorporate the use cases outlined in this chapter. Clear policy frameworks incorporating all these proposed approaches should be developed as a guide to advance the application of circular bioeconomy for the purposes emphasized here.

The concept of a circular bioeconomy offers a transformative approach toward sustainable development, particularly in addressing the significant nutrition challenges in Africa. This innovative economic model emphasizes the regeneration of natural systems, efficient use of resources, and reduction of waste, all of which are crucial for creating resilient food systems that can improve nutritional outcomes and enhance food security across the continent. Therefore, establishing robust policy support and enhancing institutional frameworks are essential steps toward leveraging a circular bioeconomy for nutritional and environmental benefits in Africa. Bioeconomy strategies from the East African Community and South Africa, which both contain food security and sustainable agriculture components and specifically edible insect production in the EAC strategy, are two initiatives worth leveraging to ensure a smooth incorporation of a nutrition-sensitive circular bioeconomy across the entire African continent (Virgin et al. 2022). However, region-wide adoption and mass realization of associated benefits would require harmonizing continental capacities, facilitating knowledge sharing, and reimagining national and continental bioeconomy plans or strategies as a conduit for exploring and expanding these opportunities.

Appendix

TABLE 8A.1—ENVIRONMENTAL PROFILE OF SOME POTENTIAL USE CASES AVAILABLE IN LITERATURE

Use cases	Impact profile						References
	GWP (kg CO2 eq)	**MEP** (kg N- eq)	**FEP** (kg P-eq)	**WU** (m3)	**AP** (kg SO2 eq)	**LU** (m2a crop eq)	
Edible insects							
Field/house Cricket	1.55–4.35	0.013–0.033	0.0003– 0.006	0.34–0.82	0.05–0.14	—	Halloran et al. (2017); Salomone et al. (2017); Suckling et al. (2020)
Black soldier fly	0.10	—	0.00004	—	0.0002	—	
Edible mushrooms							
White button mushroom	1.09–2.98	0.00003	0.00002–0.002	0.004–0.29	0.008–0.01	0.05	Robinson et al. (2018); Vinci et al. (2023)
Oyster mushroom	2.34–3.18	—	0.000465	2.42	0.00007	—	Dorr et al. (2021); Gunady et al. (2012); Gundoshmian et al. (2022)
Straw mushroom	0.84–5.40	—	0.0019–0.0425	—	0.008–0.02	—	Usubharatana (2016)
Aquaponics							
Aquaponics	2.304–20.26	0.004–0.023	0.007	—	0.020–0.40	—	Boxman et al. (2017); Chen et al. (2020); Elnour et al. (2023); Ghamkhar et al. (2022); Greenfeld et al. (2022); Hindelang et al. (2014); Hollmann (2017)
Conventional animal and plant-based proteins							
Beef	15.80–48.40	—	—	5.99–15.42	—	19.53–54.82	Berardy et al. (2019); Ferrari et al. (2022)
Chicken	2.60–5.82	—	—	4.33	—	19.22	Berardy et al. (2019); Ferrari et al. (2022)
Pork	4.33–14.79	—	—	—	—	—	Berardy et al. (2019)
Eggs	3.90–5.50	—	—	3.27	—	17.83	Berardy et al. (2019); Ferrari et al. (2022)
Soybeans	2.96	—	—	—	—	—	Berardy et al. (2019)
Legumes	1.20	—	—	9.06	—	6.96	Ferrari et al. (2022)

Note: — = data not available; AP = acidification potential; FEP = freshwater eutrophication; GWP = global warming potential; LU = land use; MEP = marine eutrophication; WU = water use.

Appendix

TABLE 8A.2—NUTRITIONAL PROFILE OF SOME POTENTIAL USE CASES AVAILABLE IN LITERATURE

Use cases	Nutritional profile				References
	Protein (%)	**Fiber** (%)	**Iron** (mg/100g DM)	**Zinc** (mg/100g DM)	
Edible insects					
Crickets	50.20–65.95	5.50–10.6	5.51–12.33	8.24–23.74	Lokeshkumar et al. (2022); Murugu et al. (2021); Musundire et al. (2014);
Beetles	32.8–44.30	6.20–14.00	14.1–23.00	14.40–26.50	Hlongwane et al. (2020)
Bees and ants	33.90–43.10	7.70–12.30	17.80–24.40	7.50–10.00	Hlongwane et al. (2020)
Caterpillars	46.3 –68.00	5.9–11.30	15.40–27.60	10.6–12.80	Hlongwane et al. (2020)
Termites	33.51–60.2	5.2–7.65	53.33–119.43	7.20–19.90	Atowa et al. (2021); Awobusuyi et al. (2021); Chakravorty et al. (2016); Kinyuru et al. (2013)
Grasshoppers	28.2–43.2	4.5–5.7	13.33–161.70	17.84–24.50	Awobusuyi et al. (2021); Ibarra–Herrera et al. (2020); Kababu et al. 2023)
Palm weevil	11.30–36.90	3.2–4.0	1.32–1.88	7.81–23.00	Adepoju and Ayenitaju (2021); Awobusuyi et al. (2021); Kavle et al. (2023); Promwee et al. 2023)
Black solider fly	33.00–48.25	7.41–10.66	30.00–220.00	30.00–120.90	Shumo et al. (2019); Zulkifli et al. (2022)
Edible mushrooms					
Edible mushrooms	13.8–38.5	—	6.9–82.6	0.61–55.7	Dimopoulou et al. (2022)
Conventional animal and plant-based proteins					
Beef	20.0–27.55	—	3.04–3.10	2.39–3.70	FoodStruct (2023); Kababu et al. (2023); Orkusz (2021)
Chicken	19.8–21.2	—	0.60	1.00	FoodStruct (2023); Kababu et al. (2023); Orkusz (2021)
Pork	17.80–27.3	—	0.87–0.90	2.20	FoodStruct (2023); Kababu et al. (2023); Orkusz (2021)
Egg	12.58	—	1.19	1.05	FoodStruct (2023)
Soybean	18.2	6.00	5.14	1.15	FoodStruct (2023)
Mung bean	7.02	7.60	1.4	0.84	FoodStruct (2023)
Cowpea	7.73	6.50	2.51	1.29	FoodStruct (2023)

Note: — = data not available; DM = dry mass.

Appendix

TABLE 8A.3—POTENTIAL ENVIRONMENTAL IMPACT OFFSETS BY SOME USE CASES RELATIVE TO CONVENTIONAL PLANT- AND ANIMAL-BASED ALTERNATIVES

Use cases	% Offsets (relative to beef)	% Offsets (relative to chicken)	% Offsets (relative to pork)	% Offsets (relative to eggs	% Offsets (relative to soybeans)	% Offsets (relative to other legumes)
Cricket	90.19	40.38	64.20	60.26	47.64	-29.17
Black soldier fly	99.37	96.15	97.69	97.44	96.62	91.67

Source: Authors.

CHAPTER 9

Bioeconomy Pathways: Experience from Africa, Asia, and Latin America

Katrin Glatzel, Detlef Virchow, Aisha Musaazi S. Nakitto, Seraphin Niyonsenga, Suresh Babu, Nandita Srivastava, and Progress Kashandula

Introduction

In 2022, the Malabo Montpellier Panel published a report that made the case for African countries to embrace a bioeconomy approach to meet their agrifood systems transformation and economic growth ambitions. The Panel systematically identified four African countries at the forefront of transitioning to a bioeconomy to better understand how different governments choose their own context-specific bioeconomy development pathways (Malabo Montpellier Panel 2022). Building on this analysis, this chapter provides a snapshot of how different countries in Africa, Asia, and Latin America are choosing their own context-specific bioeconomy entry points and pathways. It provides an update of the analyses by the Panel on the cases of Ghana, Namibia, and Uganda. In addition, this chapter shows how Brazil and Thailand have embraced a bioeconomy transition to support learning not just across borders, but across regions.

The focus in this chapter is on governance structures—policies, regulations, and institutions that form a conducive and enabling bioeconomy environment, as well as the specific entry points each government has taken to transition to a bioeconomy. This is particularly important because while requiring an overarching strategy and vision, bioeconomy approaches can range from small-scale and artisanal approaches to large, industrial-scale interventions. The key is that a bioeconomy leverages a country's or region's specific local conditions and natural competitive advantages to drive the transformation of a country's economy while providing an opportunity to positively contribute to countries' agrifood systems transformation agendas and catalyzing the untapped potential to support both climate change mitigation and adaptation

Globally, more than 70 countries already have bioeconomy or bioeconomy-related plans or strategies in place to spur economic growth while preserving the environment. In Africa, South Africa has a dedicated bioeconomy strategy and Namibia launched its own in May 2024, while more than a dozen other African countries (including Uganda) are in the process of drafting theirs. The East African Community (EAC) has become Africa's first regional economic community (REC) to draft and begin implementation of a regional bioeconomy strategy covering the period leading up to 2031–2032 (EASTECO 2022). In other regions of the world, including Asia, Europe, and Latin America, several countries have embarked on bioeconomy approaches over the past decades. Brazil and Thailand are two such examples.

This chapter is structured as follows. The second through fourth sections provide a deep-dive analysis of Ghana's, Namibia's, and Uganda's pathways toward transitioning to a bioeconomy. The fifth and sixth sections include two succinct case studies analyzing bioeconomy development in Brazil and Thailand over the past two decades, thereby providing important impetus to South–South exchange and learning opportunities.

The country analyses focus on the ingredients of a conducive enabling bioeconomy environment and highlight the partnerships between governments and other actors, including research and science, civil society, and, crucially, the private sector to elevate the bioeconomy to a central sustainable economic development pathway. The chapter concludes with a summary, drawing out the synergies and differences between the different countries' approaches, and provides a set of actionable policy recommendations for other countries seeking to develop their own bioeconomy strategies.

At the political level, continental frameworks can propel the development of sustainable bioeconomies. Several objectives and targets, such as those under Africa's Malabo Declaration commitments and the African Union Agenda 2063, are supportive of the development of a bioeconomy with frameworks for biomass production; improving value addition across bio-based value webs; and raising the quality of science, technology, and innovation (STI). In addition, strategies on energy, mining, industrialization, and climate change can accelerate the transition to a bioeconomy. At the same time, the bioeconomy can enable governments to meet their global development ambitions such as climate and biodiversity commitments, as well as to improve alignment and coherence with other countries and regions. The development of the post-Malabo Agenda at the time of writing and the Global Bioeconomy Summit in October 2024 taking place in Nairobi—and for the first time in Africa—present crucial opportunities for Africa to position itself, shape the global discourse on the transition to a bioeconomy, show leadership, and advance toward further regional integration and the development of a continental strategy.

Country Analysis: Ghana

Introduction

Ghana is endowed with diverse plant, animal, and insect species across its regions and agroecological zones. This rich diversity of biological resources is an important precursor to the country's development of an effective and sustainable bioeconomy. A bioeconomy adoption can hence enable Ghana to transform its food systems and contribute to economic growth by leveraging biomass feedstock to produce energy, biofertilizers, food, feed, pharmaceuticals, and packaging materials and support its ambitions to implement its nationally determined contributions under the Paris Agreement (2020–2030) and its green growth targets. In particular, Ghana's Fourth National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) in 2020 mentions two bioeconomy actions in the areas of (1) research and biomass and natural resources management and (2) innovative value chains (FAO 2024b).

This case study identifies the current state of the country's bioeconomy—what it has done right in terms of institutional and policy innovations and what programmatic interventions it has initiated to accelerate bioeconomy development. It also highlights opportunities to leverage Ghana's research and innovation infrastructures to develop sustainable bio-based industries and biomanufacturing.

Governance Structures: Institutions

A variety of institutional frameworks have been put in place that aim at tapping into the potential of a bioeconomy. This section explores how the institutional arrangements in Ghana have evolved to better strengthen research and innovation capacities to embrace a bioeconomy approach. The focus here is on institutions supporting the transition from fossil resources to biomass resources to create novel bio-based products.

Increasing Biomass Supply to Support the Biomanufacturing Industry

The Ministry of Food and Agriculture and the Ministry of Lands and Natural Resources have taken the lead in the implementation of government policies to improve crop biomass production that can be used as feedstock (raw material) in producing useful bioproducts for food, processing industries, and biorefineries through intensified agricultural, biodiversity conservation, afforestation, and reforestation programs (Malabo Montpellier Panel 2022). Some of the flagship programs include the following:

- The Planting for Food and Jobs program aims to improve crop productivity through extension and input supply and investments in infrastructure, such as irrigation, postharvest storage and processing facilities, and rural roads.
- The Planting for Export and Rural Development program aims to develop and regulate the tree crop subsector. The program focuses on supplying quality planting materials, primarily for cashew, coffee, coconut, oil palm, mango, and rubber.

An example of a high-potential crop for developing an agrifood bioeconomy in Ghana is cassava, for which Ghana has a 30 percent surplus compared to its population's food needs (Poku, Birner, and Gupta 2018). In this regard, cassava crop production has received special attention under the Planting for Jobs Program as an industrial crop to generate entrepreneurship opportunities along the value chain for food, feed, and bioenergy. In fact, cassava is already the second most cultivated crop in Ghana, after to maize (Ghana, Ministry of Food and Agriculture 2022). In 2021, with an average national yield of 23.77 metric tons per hectare, the country recorded production of around 25 million tons of cassava (MOFA 2022).

Scientific Research for Bioeconomy: The Ministry of Environment, Science, Technology, and Innovation and the Council for Scientific and Industrial Research

The Ministry of Environment, Science, Technology, and Innovation (MESTI) plays a prominent role in crafting a sound enabling environment to support the growth of national science and innovation frameworks. This Ministry oversees six semi-independent national agencies, of which three—the Council for Scientific and Industrial Research (CSIR), the Environmental Protection Agency, and the National Biosafety Authority—are directly linked to promoting Ghana's bioeconomy. The Ghana Atomic Energy Commission at MESTI, which oversees the Biotechnology and Nuclear Agricultural Institute, also conducts research and development (R&D) to explore the application of isotope, ionizing radiation, and other nuclear techniques and related biotechnologies for increased agricultural and economic development. Other non-CSIR research institutions include the Cocoa Research Institute of Ghana (CRIG) and the Marine Fisheries Research Division.

Transforming the Cocoa Sector With Biosciences and Technology: Cocoa Research Institute of Ghana

As a national research institution, CRIG leads the development of by-products of cocoa and other mandate crops to diversify the utilization and generate additional income for farmers. CRIG has a long history of research on tree crops of economic importance to Ghana, including cocoa, coffee, kola, and cashews. These research institutions drive the formal public sector innovation in agriculture in Ghana. CRIG's research activities have led to successes that include the isolation and characterization of the cacao swollen shoot virus and the development of diagnostic methods; identification of fast-growing, exotic, and Indigenous shade trees for cocoa; a better understanding of cocoa fermentation and flavor chemistry; and the production of by-products from cocoa wastes, including pectin, alcohol and alcoholic beverages, animal feed, soap, and cosmetics. CRIG has won several awards for research achievements both at the local level and at international fairs. In collaboration with the Animal Research Institute and the Kwame Nkrumah University of Science and Technology (KNUST), it has produced several products from cocoa pod husk, including animal feed, potash for soaps, and fertilizers; it has also successfully developed products from the apple and nut of cashew fruits, including wine, vinegar, industrial alcohol, and brandy (CRIG n.d.).

Sustainability Education and Innovation at Institutions of Higher Education

Since the early 2000s, the government has shown renewed interest in strengthening the role of tertiary institutions in developing science and technology to enhance economic development (Mensah and Gordon 2020). Several biotechnology programs have been launched, including the University of Ghana Biotechnology Research Center, the Department of Biochemistry and Biotechnology at KNUST, the Molecular Biology and Biotechnology Department at the University of Cape Coast, and the Department of Biotechnology at the University for Development Studies.

From 2014 to 2017, the University of Ghana's Institute of Agricultural Research and Tropical Agricultural Marketing and Consultancy Services (TRAGRIMACS) partnered with the United Nations Industrial Development Organization (UNIDO) to promote neem-based biopesticides in Ghana. While the university oversaw bio-efficacy and phytotoxicity studies and field trials, TRAGRIMACS was responsible for raising awareness of the project and establishing a production and distribution center. In addition to providing training for stakeholders, the project also transferred the low-cost technology to the University of Ghana to produce neem kernel aqueous extract and standardized technology for seed collection. A study in 2020 conducted by the Savanna Agricultural Research Institute and other institutes has revealed that neem-based biopesticides are as effective as synthetic chemical pesticides in fighting the fall armyworm in Ghana (Babendreier et al. 2020).

Harnessing Indigenous and Herbal Medicines for Bioeconomy: Center for Plant Medicine Research

Efforts to promote traditional and herbal medicine practices have a long history in Ghana, starting with the creation of the Ghana Psychic and Traditional Healers Association in the 1960s. Forty years later, the Traditional Medicine Practice Act of 2000 (Act 575) was passed to regulate the use of herbal medicines and the practice of traditional medicine. In 2011, herbal clinics were piloted in selected government hospitals nationwide, and in September 2012, the Ministry of Health integrated the use of clinical herbal medicine into Ghana's main healthcare delivery system. The Center for Plant Medicine Research (CPMR) was established in 1975 by the government of Ghana. The center is located in Mampong-Akwapim and has a vision of "making herbal medicine a natural choice for all" (Asare 2015). The center is mandated to backstop the herbal medicine industry by conducting research and manufacturing herbal medicinal products. The center has established infrastructures and human resources to conduct research in different fields such as phytochemistry, pharmacology, and biotoxicology to ensure the safety and efficacy of plant-based medicinal products. As an example, the center has conducted research on 15 herbal medicinal plants to formulate and commercialize three products—namely *Enterica, Dyspepsia*, and *Natural Pain Killer (NPK) 500 capsule*—used in the management of peptic ulcer disease. Those Indigenous plants include *Morinda lucida*, *Vernonia amygdalina*, *Lantana camara*, *Spondias mombin*, and others (Kumadoh et al. 2021). Indigenous and herbal medicine in Ghana received a further boost when CPMR accepted the efficacy of the Immunim herbal product for treating COVID-19 in Ghana in 2022. CPMR also works on other herbal medicines such as Mist Nibima to treat malaria and COVID-19 and *Cassia sieberiana* for dysmenorrhea and gastric ulcer pain (Archer et al. 2020; Kumatia 2021).

Governance Structures: Policies

Over the past two decades, the government of Ghana has made tremendous efforts and robust commitments toward enhancing the bioeconomy via several policy innovations that have sustainability goals in common. The overarching goals have been to alleviate poverty and stimulate accelerated national economic development. While the institutions largely promote STI, the production and processing of renewable biomass are underpinned by agricultural and forestry policies. At the same time, climate change, environmental, and waste management policies provide an important impetus for developing bioproducts and biosolutions.

Agricultural and Forestry Policies to Facilitate Biomass Supply

Developing a sustainable bioeconomy requires adequate production and availability of biomass. This implies that an increase in the productivity of traditional cropping systems is a significant precondition for the successful development of a bioeconomy (Scheiterle and Birner 2020). This productivity increase should be done sustainably and should meet the sustainability goals and objectives of the country. Ghana has a vibrant and effective institutional framework with which to drive the formulation, implementation, and development of policies that can contribute to the development of a bioeconomy.

Alongside agricultural biomass, Ghana's policymakers have sought to increase renewable biomass from the forestry sector. In 2015, the government initiated the establishment of woodlots and forest plantations on 500,000 hectares of degraded land, to be cultivated by 2040 (ECREE 2015). In 2020, 226,000 hectares of degraded forest area were restored with cocoa landscape. Similarly, in 2021, the Circular Bioeconomy Alliance, with funding from AstraZeneca, initiated a Community Living Lab to promote bioeconomy for livelihood improvement through forest landscape restoration in Atebubu and Wiase communities located in the Bono East Region in central Ghana, near Lake Volta and the Digya National Park. The project aims to restore 3,000 hectares of degraded land and plant at least 3.9 million trees by 2025. Also, as a strategy to promote a bio-based renewable energy agenda, more biomass would be produced from forest residues as offcuts from timber and as a by-product of the processing of timber or agricultural products. Under the Ghana Forest Plantation Strategy for 2016 to 2040, the country aims to ensure biomass availability from forest residues by establishing and managing planted forests, promoting investment in forest plantation, creating employment and sustainable livelihoods, and increasing investment in R&D.

Waste Management and Recycling

In 2010, the Ghana National Energy Policy was promulgated: it seeks to enhance the transformation of waste (including agricultural waste and other biomass) into energy through various technological approaches. To ensure sustainability, the policy offers various bioeconomy opportunities for investments in the renewable energy subsector. First, Ghana's Renewable Energy Act of 2011 (Act 832) was particularly effective; it enshrined a feed-in-tariff scheme that was instituted for electricity generated from renewable energy sources such as biomass. It was designed to support the target of 10 percent renewable energy in the national energy mix and to ensure that investors obtained a good return on their investments (UNEP 2015). In 2020, as a result of these interventions, four biomass-fired cogeneration plants were operating in Ghana, with a combined installed capacity of 4,034 kilowatts and an average annual production of 12.3 gigawatt hours (ECREE 2015). Another important initiative to support the development of the bioeconomy was Ghana's program to install biomass/waste-to-energy power plants by 2020, with capacities ranging from 50 to 100 megawatts. As part of this strategy, by 2016, the Ministry of Power reported 100 biogas plants constructed nationwide.

Programmatic Interventions: Partnerships Between Public and Private Sector and Research Organizations

Several of Ghana's existing programmatic interventions support the development of a bioeconomy. These programs focus on a wide range of sectors including agriculture and climate change, energy, biodiversity, and water and sanitation. The following section presents an overview of some key interventions.

The Private Sector And Bioeconomy: Cashing in on the Cassava Crop

Cassava is a major staple crop in Ghana and has the advantage of being able to produce economic yields even under marginal production conditions. The crop accounts for approximately 50 percent of all root and tuber production in the country and is second only to maize in terms of area planted. It is consumed in all regions and by all ethnic groups and is therefore considered to be a primary food security crop. Cassava starch can be converted into ethanol production, which is a key ingredient in alcoholic drinks and pharmaceuticals such as hand sanitizers. The Presidential Special Initiative on cassava, commissioned in 2003, was aimed at developing industrial cassava starch production for both the domestic and international markets. In the process, it also aimed to improve the socioeconomic conditions of Ghana's smallholders. A new factory, Ayensu Starch, was commissioned in 2004 to supply a growing domestic and global market for starch, in turn creating a market for cassava growers. The firm, however, was plagued by high operational costs and technological challenges that on two occasions culminated in temporary shutdowns, thus necessitating a more focused and sustainable operational strategy. In 2012, to revive the program, the government introduced a concessionary excise duty waiver for manufacturers who used local raw materials. Within six months, Ayensu Starch signed an exclusive supply agreement with Guinness Ghana Breweries Limited to supply high-quality cassava starch, which the brewery uses to produce one of its brands of beer for the domestic market. This was soon followed by the production from cassava starch of Accra Brewery's beer brand, Eagle Lager. Cassava starch has since also found a market in the production of biscuits and other household products. About half of the Ayensu Starch factory's cassava is grown on its own farms, while the rest is sourced from about 400 smallholder outgrowers who are issued quality guidelines that they must meet. Waste products from the process of extracting starch, such as peels and pulp, are then sold to local livestock enterprises, which earns the company additional revenue. The simple intervention to attract private sector players in the use of cassava and starch has kickstarted a revolution in Ghana's cassava sector, with its products and by-products featuring in food processing, baked products, paperboard manufacturing, domestic plywood outputs, and bioethanol and biogas (Poku, Birner, and Gupta 2018).

Bio-Based Solutions for Community Development: Biopesticides

In 2021, Tibourataa Women Group, supported by the German Agency for International Cooperation (GIZ), launched a neem seed processing unit in Wa Municipality in the Upper West Region of Ghana. The processing unit produced 2,000 liters of neem oil and 7,000 kilograms of neem cake in one year following its launch. The group subsequently expanded its operations into biopesticide production using neem oil with their own brand, Neem Crop Protector, which after efficacy trials received certification from the Ghana Environmental Protection Agency. This allowed the Tibourataa Women Group to expand the market for biopesticide as a safe and sustainable alternative to chemical pesticides by partnering with 20 agri-inputs dealers to distribute their products to farmers across the country farmers to control crop pests. Further, since its establishment, the group has created 500 jobs for women as neem seed collectors.

Biogas Technology and Business for Sustainable Growth

Biogas Technology and Business for Sustainable Growth (BTBSG) was a 2013 to 2016 program to assist Ghana's green industries. It was implemented by UNIDO in partnership with the Ministry of Trade, Industry, and Energy of Korea and the Korea Institute of Energy Technology Evaluation and Planning. The BTBSG program builds on empirical evidence on the state of biogas industries in Ghana and lessons drawn from past and current biogas initiatives in the country. The program's two main aims are to enhance access to clean energy through the promotion of industrial-scale biogas technologies in the form of an integrated technology transfer and to support the development of biogas enterprises in Ghana. Several biogas plants have been created at abattoirs, homes, health and educational institutions, and various other locations across the country.

Conclusion

Ghana's richness in biodiversity and availability of large stocks of biomass makes the country highly suitable for a thriving bioeconomy for agrifood systems transformation and a transition from fossil fuels to harnessing biomass resources; in particular, bio-based industries and the use of bioenergy sources appear to be a strong entry point to Ghana's emerging bioeconomy. Ghana's Renewable Energy Act, 2011 (Act 832) was particularly effective in promoting renewable energy sources from biomass. As Ghana launched the process of developing its national bioeconomy strategy in December 2022, many past and present government policies and programs—particularly in the agricultural, energy, and forestry sectors—contain components that promote various aspects of the bioeconomy and provide a solid foundation upon which to build (Virchow et al. 2016). The development of strategic bioeconomy blueprints will not only help prioritize investments and government interventions; it will also guide a policy agenda for bio-based economic growth and sustainable development.

Country analysis: Namibia

Introduction

Namibia's pursuit of a sustainable bioeconomy is marked by a deep-rooted commitment to environmental conservation and sustainable development, leveraging its rich biodiversity and natural resources. This commitment is demonstrated through comprehensive governance structures, institutional innovations, policy frameworks, and strategic objectives that collectively drive the country toward a green growth trajectory. This report outlines Namibia's development toward a bioeconomy by focusing on governance structures, in particular institutions and policies, as well as knowledge exchange with international platforms and other countries and regions, which supported Namibia in driving the transition to a bioeconomy. This section features some examples of beneficial partnerships between the different stakeholders on the way to a bioeconomy, and it concludes with some policy recommendations.

This analysis is based on the Namibia case study from the Malabo Montpellier Panel (2022) and supplements that report with further and updated information on the development of the bioeconomy in Namibia, with a focus on the governance structures and the identification of Namibia's chosen bioeconomy pathway. Namibia's bioeconomy strategy was launched on May 6, 2024, and further aligns many of its existing institutions and policies (Republic of Namibia, Ministry of Higher Education, Training and Innovation and National Commission on Research, Science, and Technology 2024).

Governance structures: Institutions

Namibia's approach to bioeconomy is supported by a robust framework involving various government bodies, research institutions, private sector entities, and civil society organizations. Key government players include the ministries of Higher Education, Technology, and Innovation (MHETI); Environment, Forestry, and Tourism (MEFT); Agriculture, Water, and Land Reform (MAWLR); and others, such as the National Planning Commission (NPC). They play pivotal roles in shaping and implementing bioeconomy-related policies.

Their efforts are complemented by private sector engagement through bodies like the Namibia Biomass Industry Group (N-BiG) and the Charcoal Association of Namibia (CAoN, formerly the Namibia Charcoal Association), which drive the biomass sector forward. In addition, civil society's involvement ensures that bioeconomy development is inclusive, benefiting a wide range of stakeholders and contributing to the broader societal good.

In Namibia, the different roles and responsibilities for bush control and sustainable bush use are a good example of how complex the institutional arrangement for implementing the bioeconomy approach can be. Since MEFT is responsible for promoting the rehabilitation of degraded land (through bush encroachment) and promoting sustainable resource management and utilization, it is essentially the main regulatory authority for the harvesting of bush biomass. As the harvested bush biomass can be valorized through numerous value chains (such as charcoal, wood chips, and bush feed), the Ministry of Industrialization and Trade (MIT) is involved in supporting the existing value chains and developing new ones. In addition, MAWLR plays an important role in promoting appropriate forms of grazing land management to reduce or completely prevent the further spread of the bush and even reduce bush encroachment. MAWLR also strengthens all-inclusive approaches that enable all stakeholders to benefit equally. In addition, three other ministries (Mines and Energy; Urban and Rural Development; and Labour, Industrial Relations, and Employment Creation) play a role in the implementation of the biomass strategy, as well as many stakeholders from associations and civil society (three farmers' associations, an umbrella organization of NGOs supporting natural resource management at the community level, three Namibian universities, two federal agricultural offices, Namibia's national electricity producer, and two commercial banks). In addition, the sector's two industry associations, N-BiG and CAoN, play a crucial role in countering the ecological and economic problem of bush encroachment through various value chains and enabling economic benefits in the valorization of the bush through their association members. Sectoral coordination is crucial for synergizing efforts. A proposed national coordination committee, proposed in the National Strategy for the Sustainable Management of Bush Resources 2022–2027 (NSSMBR), should aim to facilitate information exchange, knowledge sharing, and policy implementation among ministries, civil society, and the private sector for improved adaptive capacity. In addition, the Food and Agriculture Organization of the United Nations (FAO) and other agencies have also supported the bioeconomy of the bush sector through various projects, including promoting sustainable bush processing value chains and restoring ecosystems through sustainable forest and land management in Namibia. Part of the broader rangeland management includes the promotion of sustainable land management practices such as sustainable bush thinning and harvesting (including charcoal production, beekeeping, and sustainable thatch grass harvesting), and other practices such as promotion of selected value chains (including poultry rearing and marula oil and juice production), will be adopted as alternatives to destructive land and forest use practices. Moreover, Namibia is a good example of the certification of charcoal.

NPC and the Namibia Investment Promotion and Development Board (NIPDB) are closely linked entities within the framework of national development and economic growth. NPC is tasked with overarching development planning and policy formulation in Namibia. It crafts long-term strategies such as Vision 2030 and the successive National Development Plans (NDPs)—and especially NDP 5—which outline the country's economic objectives, developmental goals, and the roadmap for achieving them. As such, NPC sets the stage for sectoral priorities, socioeconomic development targets, and investment needs. NIPDB, on the other hand, functions as a dynamic interface for investors and as a facilitator for investment in Namibia. Established in 2021, NIPDB is strategically located in the Office of the President of Namibia and operates within the strategic direction and priorities established by NPC, aiming to attract, promote, and facilitate investment that aligns with the national development goals. By doing so, NIPDB plays a critical role in realizing the objectives laid out by NPC, focusing on sectors identified as priority areas for growth and development such as renewable energy, agriculture, and tourism—as well as supporting the development of micro, small, and medium enterprises including start-ups in the bioeconomy. The symbiotic relationship between NPC and NIPDB ensures that investment promotion efforts are strategically aligned with NDPs and policies. This coordination is vital for harmonizing investment activities with national priorities, thereby promoting sustainable economic development, job creation, and wealth generation for Namibia. Through collaboration with the biomass sector and N-BiG, NIPDB has decided to include bush biomass in its renewable energy portfolio and is very interested in the further development of the biomass sector.

Governance Structures: Policies

The bioeconomy policy framework in Namibia is informed by NDPs and international commitments. It includes Vision 2030, related NDPs, and sector-specific policies that emphasize the sustainable use of natural resources, biodiversity conservation, and the transition to a knowledge-based economy. As outlined in the appendix of the Bioeconomy Strategy, Namibia's policy landscape concerning the bioeconomy is both rich and diversified, reflecting the multifaceted nature of bioeconomy development. In particular, Appendix 4 of the Bioeconomy Strategy lists all directly and indirectly relevant policies (Republic of Namibia, Ministry of Higher Education, Training and Innovation and National Commission on Research, Science, and Technology). Policies range from detailed strategies aimed at specific issues, such as the management of bush encroachment, to broader NDPs and visions that encapsulate the principles of sustainability and resilience. For instance, the Growth at Home Strategy focuses on industrialization, manufacturing, and value addition to drive economic growth. It supports value addition, market access, and investment climate improvement, complementing the national bioeconomy strategy by leveraging bioresources to create new value chains, benefiting both rural and urban communities. This policy mosaic facilitates a nuanced approach to leveraging the country's biological resources, addressing immediate environmental challenges while laying the groundwork for long-term economic and social prosperity. These strategies are not stand-alone but are integrated into the wider economic and environmental policy landscape, reflecting a holistic approach to national development.

The recently launched Namibia Sustainable Bioeconomy Strategy for 2024–2029 aims to integrate and coordinate existing institutions and policies, aligning with Vision 2030, NDPs, and Sustainable Development Goals (SDGs) for economic empowerment and poverty eradication. Facilitated by the National Commission on Research, Science, and Technology (NCRST) as an agency of MHETI, the strategy was developed by NCRST in collaboration with FAO. The strategy leverages spillover benefits from agriculture, health, and the environment, emphasizing sustainable and circular practices. A Bioeconomy Multisectoral Working Group (BMWG) comprising 24 entities from government, private sector, NGOs, and educational institutions, conducted a comprehensive analysis of Namibia's bioeconomy landscape. The strategy serves as a sustainable development framework, avoiding resource overexploitation and integrating bioeconomy activities into the national economy through research, development, and innovation. The action plan translates the strategy into concrete measures, focusing on priority components identified by the NCRST analysis. Strategic focus areas include agriculture, health, natural resource management, and cross-cutting issues, identified through regional consultations with stakeholders. Challenges and opportunities related to the bioeconomy were documented in the Bioeconomy Stocktaking and Analysis Report completed in 2021. FAO's support included a stocktaking and analysis exercise to establish the bioeconomy baseline in Namibia, facilitating a participatory process at national and regional levels, and enabling knowledge exchange with international experts from the International Sustainable Bioeconomy Working Group. The strategy incorporates a comprehensive monitoring framework with indicators related to biomass production; processing in agrifood systems; use of biomaterial; and impacts of services such as logistics, transport, retail, research, and tourism. NCRST will oversee the implementation to ensure the strategy's objectives are met, with BMWG continuing to report periodically on various bioeconomy programs and initiatives by agencies, ministries, and the private sector.

The NSSMBR, launched by MEFT under the guidance of various stakeholders, exemplifies a comprehensive multistakeholder approach to managing the rapidly growing biomass-based economy. The formulation of the NSSMBR followed a detailed and inclusive methodology. It began with a scoping report to identify governance gaps, followed by a consultative process involving key stakeholders, including government ministries, private sector entities such as N-BiG and NamPower, civil society organizations such as the Namibia Agriculture Union and the Namibia National Farmers Union, and academic institutions such as the Namibia University of Science and Technology (NUST) and the University of Namibia (UNAM). The process included thematic discussions on specific issues and involved a specialized task force within MEFT. This approach ensured that the strategy integrated diverse perspectives, industry needs, and extensive research, aligning with national policies and international agreements for a holistic approach to sustainable bush resource management. The strategy aims to rehabilitate degraded land, develop and promote bush value chains (such as biochar, wood pellets, and charcoal), and ensure responsible bush control practices. It aligns with Namibia's constitutional commitment to ecosystem maintenance and sustainable resource use, reflecting MEFT's strategic pillars and international commitments to the UNFCCC, Convention on Biological Diversity (CBD), and Convention to Combat Desertification.

The NSSMBR is intricately linked with various national policies and frameworks, reflecting its integration into broader development agendas. Firstly, it aligns with Namibia's overarching Vision 2030 and the NDPs, contributing to poverty alleviation, economic growth, and environmental sustainability. Secondly, intersecting with environmental conservation policies such as the National Biodiversity Strategy and Action Plan (NBSAP) and the Climate Change Policy, the NSSMBR supports land restoration, biodiversity conservation, and climate resilience. Additionally, it complements rural development strategies by diversifying the rural economy and creating employment opportunities, in alignment with the Rural Development Policy. Moreover, the NSSMBR supports energy policies by advocating for the utilization of bush biomass as a renewable energy source, consistent with the Renewable Energy Policy and the National Energy Strategy. It further aligns with agriculture and livestock policies by promoting sustainable land management practices and enhancing agricultural productivity, as outlined in the National Agriculture Policy and the Livestock Development Strategy. Through these alignments, the NSSMBR integrates the sustainable management of bush resources into broader national development agendas, fostering environmental sustainability and socioeconomic development. Finally, the strategy's implementation will contribute to several SDGs by creating employment opportunities, fostering economic growth through innovative value chains, and ensuring the conservation and sustainable use of terrestrial ecosystems.

Namibia's Food Systems Summit Pathway mentions that as a dry country, Namibia should promote regenerative agricultural practices and microorganism build-up to ensure soil fertility, moisture retention, and carbon storing to reverse biodiversity loss, halt bush encroachment, improve pastures, and restore the ecosystem to unlock ecosystem benefits. For a dry climate, it is commendable that some beneficial microbes have been identified, opening prospects for inoculant technology or biofertilizers that can replace synthetic nitrogen-based fertilizers.

Gateway Sectors to Drive the Transition to a Bioeconomy

According to Namibia's recently published Bioeconomy Strategy, the strategic focus areas for the realization of a sustainable bioeconomy in Namibia include agriculture, health, natural resource management, and cross-cutting issues. In agriculture, which contributes up to 5 percent of Namibia's GDP and employs nearly 170,000 people, the focus is on enhancing production and resilience through innovative bioproducts and reducing post-harvest losses due to climate change. In health, there is a need for innovative diagnostic tools, vaccines, and therapeutics, with an emphasis on leveraging Indigenous plants for primary healthcare through access and benefit-sharing mechanisms. Natural resources management prioritizes conservation and sustainable use, balancing ecological sustainability with economic progression. Cross-cutting issues include infrastructure, value addition, standards, capacity building, and policies. Challenges in this area involve insufficient research, development, and innovation and capacity for rural communities to create value chains and process raw materials into finished goods. Addressing these challenges can drive a sustainable bioeconomy.

Besides these strategic focus areas, there are specific economic sectors that have proven to serve as gateway sectors for the transition to a bioeconomy due to their significant contribution to the country's economy, environmental sustainability, and social development. These sectors offer the opportunity to introduce a biomass-based economy and utilize the country's abundant biomass resources for sustainable development and economic growth. Besides the obvious sectors that support the transition to a bioeconomy (especially agriculture, fisheries, and forestry), the relevant sectors include the following.

The energy sector allows biomass to be used as a renewable energy source mainly for electricity generation, reducing dependence on imported fossil fuels and promoting energy security. Biomass power plants such as NamPower (see below) can be established to generate electricity mainly from bush biomass, thus contributing to rural electrification and reducing greenhouse gas emissions.

The tourism industry, which draws on Namibia's famously diverse landscapes, rich biodiversity, and vibrant cultures, is a cornerstone of the country's economy. By capitalizing on its natural assets such as national parks, game reserves, and heritage sites, Namibia has established itself as a leading ecotourism destination. As part of the transition to a bioeconomy, sustainable tourism practices are being promoted that emphasize environmental protection, community involvement, and cultural preservation. Initiatives such as eco-lodges powered by renewable energy sources and conservation areas practicing sustainable land management contribute to the transition to the bioeconomy by aligning tourism with the principles of environmental sustainability and resource efficiency.

The livestock sector, especially cattle (and game) farming, is an integral part of Namibia's broader agricultural sector and rural economy. As one of Africa's largest beef exporters, Namibian meat production plays a crucial role in food security, job creation, and export earnings (Workman 2024). To improve the sustainability and resilience of the meat production sector, initiatives such as holistic land management, restoration of the bush savannah as the predominant grazing zone, improved grazing practices, and the use of bush biomass to supplement livestock feed are being promoted. These measures not only improve the productivity and profitability of livestock farming but also contribute to the conservation of biodiversity, soil health, and climate resilience and are therefore in line with the principles of the bioeconomy.

A unique aspect of the Namibian emerging bioeconomy is the strategic focus on the utilization of bush biomass. This specific industry sector aims not only to combat the negative effects of bush encroachment on productivity (livestock and wildlife) and the country's biodiversity but also to promote economic activities in the processing and utilization of biomass. The conversion of bush biomass into products supports farmers and improves living conditions in rural areas. Examples include wood chips (and, in the future, also pellets) and charcoal for renewable energy; animal feed to improve the climate resilience of an important domestic and export sector; wood cement, wood–plastic composites, and fiberboards as building materials for the domestic and export sector; and biochar as organic fertilizer for farmers and as an export product to create new industries. The focus on creating sustainable value chains from natural resources is an example of Namibia's commitment to an ecologically sustainable and economically viable bioeconomy. Studies suggest significant benefits through commercial use of woody biomass for Namibia's economy, estimating US$4 billion over 25 years if 15.8 million hectares are sustainably thinned. Increased livestock production, biomass value chains, and groundwater recharge contribute to this economic boost. Farmers and companies are tapping into these opportunities. Developing bush-based industries is crucial for sustainable financing of savannah restoration efforts, driven by the abundance of biomass and its potential for economic growth (Archer et al. 2017; Birch et al. 2017; Trede and Patt 2015). This shows that bush encroachment in Namibia as an environmental challenge has huge potential for developing the bioeconomy transition in the country. NUST and UNAM are key research entities supporting this effort, with strong departments in sustainable agriculture, environmental science, management, and engineering. They partner with the bush-biomass sector, including N-BiG, and in the last few years, with the MEFT/GIZ Bush Control and Biomass Utilization program. For further research, these public research organizations may need incentives to shift traditional priorities. This can be achieved through targeted funding, grants, and collaborations with the biomass industry in public–private partnerships, including global research bodies. Additionally, policy frameworks, tax incentives, recognition, capacity building, stakeholder awareness, and community engagement are essential for promoting this shift.

By integrating sustainable practices, innovation, and value creation into these sectors, Namibia can utilize its natural resources more efficiently, promote economic diversification, and achieve long-term environmental and social sustainability. In doing so, these sectors not only hold the promise of economic diversification, but also the potential for job creation and community development. Collaboration between government agencies, private sector stakeholders, local communities, and international partners is critical to realizing the full potential of Namibia's bioeconomy transition.

In addition to the gateway sectors mentioned above, there is an urgent need to involve all relevant stakeholders, including ministries, in the process of transitioning to a bioeconomy. The methodology used to formulate the NSSMBR is an excellent example of a comprehensive and inclusive process. Furthermore, the development of Namibia's Bioeconomy Strategy is another good example of how to include all relevant stakeholders and sectors.

Partnerships Between Public and Private Sectors and Research Organizations

The emerging interest in developing a bioeconomy has triggered numerous initiatives to promote its growth in Namibia. This includes a strong focus by both the private and public sectors at national and international levels on improving biomass-based value chains, which requires a robust framework for the sustainable management and utilization of biomass-based resources. The country's investment in R&D, particularly in the areas of sustainable agriculture, biomass utilization, and renewable energy, is central to unlocking the potential of the country's natural resources. This focus on innovation not only strengthens Namibia's economic competitiveness but also contributes to global knowledge and technological progress in the field of sustainable practices. In the strategy, the government will facilitate investments and access to bank loans by developing financial tools such as zero-collateral loans for farmers and entrepreneurs in the bioeconomy, in collaboration with the private sector, including Agribank and Development Bank of Namibia. Partnerships with United Nations agencies, the European Union (EU), the United States Agency for International Development, the UK Foreign, Commonwealth and Development Office, and other bilateral partners are also seen as a key action areas. Some examples of FAO support on specific topics include strengthening the capacities of the government on a range of topics (small-scale fisheries for gender equitable and climate resilient food systems and livelihoods; the sustainable utilization and management of wildlife resources for improved food security, nutrition, and livelihoods; agri-business value-addition through tailored interventions including training, post-harvest equipment, infrastructure, transport, and agro-industrial technologies, among others). There is also a specific project on integrated landscape management to reduce, reverse, and avoid further degradation and support the sustainable use of natural resources in the Mopane-Miombo belt of northern Namibia. FAO also featured the example of a Namibian cooperative that produces several bioeconomy products with marula, the national plant. Namibia is also part of the Southern Africa Innovation Support Programme, which aims to enhance innovation cooperation between several STI ministries in the region and the Southern African Development Community.

Three examples from very different sectors can illustrate this interaction between investment in innovation through partnerships between the public and private sectors and research institutions.

Namibia's multicultural society is rich in traditional knowledge of wild foods, medicinal plants, and natural remedies. Indigenous plants such as devil's claw, marula, and Commiphora are increasingly being commercialized (GIZ 2019). The marula oil industry in particular highlights the importance of sustainability and community involvement in economic development and resilience, especially in rural areas. Marula oil, a traditional Namibian product, is known for its high antioxidant content, making it one of the most stable natural oils. The Eudafano Women's Cooperative, with around 2,500 members, produces both food and nonfood products from marula, including cosmetics sold to international brands like The Body Shop. This cooperative operates under circular bioeconomy principles, promoting green employment and food security, aligning with Namibia's National Bioeconomy Strategy (2023–2028). The marula oil industry has been crucial in job creation and poverty alleviation, particularly for women who are primarily involved in fruit collection and processing (UNCTAD 2021). Improved processing techniques, certification, and standardization have enhanced the quality of Marula oil, enabling access to global markets, especially in the cosmetics and personal care sectors (USAID 2022). The international recognition of Namibian marula oil has driven demand in Europe, North America, and Asia (USAID 2022). The industry's growth, supported by government and NGO initiatives, has been bolstered by sustainable harvesting practices, ensuring the long-term viability of marula trees and the continued success of the industry (such as GIZ 2019; Sequa 2022).

NamPower, Namibia's national power utility, is moving ahead with its 40-megawatt Otjikoto Biomass Power Station near Tsumeb. The estimated US$104 million power plant will generate electricity from wood chips from bush biomass and is expected to ensure energy security, affordability, and environmental sustainability. The project is part of NamPower's strategy and business plan to diversify the country's energy mix and is in line with the Ministry of Mines and Energy's decision to build new power plants to increase Namibia's capacity. It supports national policies such as Harambee Prosperity Plan II and the Renewable Energy Policy and aims to generate 70 percent of energy from renewable sources by 2030, contributing to 80 percent energy self-sufficiency. The project aims to establish a local biomass fuel supply chain, promote environmental sustainability, and restore biodiversity. In addition to improving energy security, it aims to combat bush encroachment and promote agriculture and groundwater while reducing carbon emissions. The success of the project could pave the way for similar initiatives across Namibia, especially in regions affected by bush encroachment. In the project's feasibility study, the Oshikoto Region was identified as an optimal location due to the socioeconomic impact and availability of biomass. In addition to its own initiative, NamPower seeks support from the NAMA Facility, a funding mechanism that assists developing countries in implementing nationally appropriate mitigation actions (NAMAs). The NAMA Facility could provide financial assistance to support project development, capacity building, and policy reforms aimed at promoting sustainable biomass utilization and reducing greenhouse gas emissions.

The Sustainable Resources Verification Scheme (SURE) is a certification system accredited by the EU Commission and developed for the production, supply, and processing chains of solid and liquid biofuels per the requirements of the EU's Renewable Energies Directive II. The SURE system verifies the sustainable production and use of forestry and agricultural biomass as well as residual and waste materials primarily within the EU. However, with the increasing demand for biomass, the certification system will also become more important outside the EU to verify the sustainable production of biomass imported into the EU. The SURE certification scheme is approved in the EU alongside other scheme providers (such as ISCC and REDcert) and has recognized N-BiG as the national supporting body (NSB) of SURE for Namibia. Through collaboration with NSBs, SURE addresses regional specifications focusing particularly on the proof of legality of biomass harvesting as well as analyzing the legal framework and recommending further development of the certification scheme. In addition, NSBs are in constant dialogue with the economic actors and enable a practice-oriented knowledge transfer. Due to this, NSBs are instrumental in expanding the SURE system in Africa as well as for all SURE-certified biofuels exported from Africa to the EU.

Conclusion

Namibia's journey toward a bioeconomy is guided by robust governance structures and policies, facilitating collaboration between government agencies, research institutions, private sector entities, and civil society organizations, as well as subnational levels/regions, and international experts. These stakeholders play crucial roles in shaping and implementing bioeconomy policies, fostering inclusive development, and ensuring the sustainable management of natural resources. The intricate institutional arrangements, involving ministries such as MHETI, MEFT, MAWLR, and MIT, underscore the multifaceted nature of bioeconomy development and the need for coordinated efforts across sectors. In particular, NCRST has a key role to play in the coordination, management, and monitoring of the strategy. The bioeconomy comprises primary production such as agriculture, forestry, fisheries, aquaculture, and industries that use or process biological resources. Therefore, the Strategy simultaneously sets out a framework for the conservation of these resources for future generations. BMWG will also be instrumental in the country and in the region. It consists of 24 entities (9 government ministries; 5 private companies; and 10 NGOs, public enterprises, and higher education institutions).

Additionally, policies such as the NSSMBR and Vision 2030 provide a comprehensive framework for integrating bioeconomy principles into national development agendas.

Furthermore, partnerships between the public and private sectors, as evidenced by initiatives such as the Otjikoto Biomass Power Station and the Sustainable Resources Verification Scheme, highlight the importance of innovation and collaboration in driving sustainable economic growth. These initiatives leverage Namibia's abundant natural resources, such as biomass and renewable energy, to create economic opportunities, promote environmental sustainability, and enhance energy security.

Overall, Namibia's bioeconomy transition represents a holistic approach to development, integrating environmental conservation, economic diversification, and social inclusion. Through strategic investments in key gateway sectors, Namibia is poised to unlock the potential of its natural resources, drive innovation, and create a sustainable future for generations to come. Collaboration, innovation, and policy coherence will remain essential as Namibia continues its journey toward a resilient and inclusive bioeconomy.

Namibia is striving for a sustainable bioeconomy, which is associated with challenges and opportunities. A good example of such a key challenge is the expansion of bush encroachment, which requires continuous research and innovation. However, this challenge also presents an opportunity to develop new industries, improve ecosystem services, and boost economic growth. Namibia's focus on the use of bush biomass and the development of value chains shows how challenges can be turned into green growth opportunities. The same dynamic happens with the sustainable use and valorization of Indigenous and traditional knowledge, such as the multiple uses of the marula tree.

Namibia's commitment to sustainable development and economic diversification is reflected in a holistic approach to governance, policy, and strategy. Various initiatives demonstrate this commitment by addressing environmental issues while leveraging them for economic growth and livelihoods. Namibia's proactive stance is evident in policy innovation, research, and international collaboration that provides valuable insights to address challenges such as technological constraints and market access issues.

Namibia also emphasizes social inclusion and community empowerment. By involving local communities in resource management and income distribution, the country contributes to poverty reduction and social development. Challenges have included limited resources and funding require incentives, regulations, and increased funding for sustainable resource management and economic development. Namibia's comprehensive strategies and initiatives provide a roadmap for overcoming obstacles and seizing opportunities for economic diversification, job creation, and environmental resilience. Through continued commitment to sustainability and inclusion, Namibia is poised to realize the potential of its emerging bioeconomy and create prosperity for all citizens. Namibia's strategic pursuit of a bioeconomy demonstrates visionary leadership in sustainable development, showcasing how innovative policies and collaborative efforts can align economic growth, environmental conservation, and social inclusion. By leveraging biodiversity and fostering innovation, Namibia exemplifies a holistic approach to sustainable development. Lessons from Namibia emphasize integrated policy frameworks and cross-sectoral collaboration, serving as a global model.

Effective sector coordination, facilitated for example by a national coordinating committee involving various stakeholders, is essential for the implementation of biomass-based strategies in Namibia, especially for the implementation of the future bioeconomy strategy. This coordination drives activities, boosts adaptive capacity, and ensures sustainable management practices, positioning Namibia as a leader in sustainable development.

Country Analysis: Uganda

Introduction

Uganda's rich biodiversity has enhanced the development of its bioeconomy, as seen in the use of biomass in all its economic sectors. Biomass and waste provide 89 percent of the total energy supply and 98 percent of domestic energy production nationally; both with an upward trend (IEA 2024). Given the extensive use of biomass, the government of Uganda recognizes that sustainable biomass usage is critical and also strives to develop a bioeconomy by promoting low-carbon-intensive pathways for economic development, which is an area of focus in the Uganda Vision 2040 and the NDP III 2020/21–2024/25. Therefore, the government encourages the participation of the private sector in countrywide strategies for planting multipurpose trees, shrubs, and energy crops, as seen in the Running Out of Trees (ROOTs) Campaign, to ensure the sustainable supply of biomass for generating thermal energy and electricity, conserving biodiversity, mitigating climate change, and ensuring clean air, as well as food and energy security (FAO 2023a; Uganda, Ministry of Energy and Mineral Development 2018b). The government and its partners also actively support science and research, including developing clean and efficient energy technologies and reducing agricultural waste through agro-processing to form biogas, food products, and animal feed for a circular bioeconomy. This case study assesses governance structures (institutions and policies), as well as key partnerships between the public and private sectors and with research organizations, which have contributed to Uganda's progress in achieving a thriving and sustainable bioeconomy.

Governance Structures: Institutions

Uganda's growth in agricultural (including crop, livestock, fisheries, and forestry), energy, and health sectors, coupled with investment in science, technology, engineering, and innovation, has supported the development of its bioeconomy. This growth is underpinned by various institutions such as the National Agricultural Research Organisation (NARO) and Makerere University's College of Agriculture and Environmental Sciences (CAES), both of which have dominated Uganda's research into sustainable agriculture and food security (UNCST 2023). This section reviews the government institutions that are contributing to the growth of the country's bioeconomy.

National Agricultural Research Organisation

NARO, an agency of Uganda's Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), is mandated to coordinate and oversee all aspects of public-funded agricultural research in Uganda. NARO conducts agricultural research on crops, livestock, fisheries, forestry, agro-machinery, natural resources, and socioeconomics. The organization comprises a Governing Council, a Secretariat, and 16 Public Agricultural Research Institutes spread across the country, which include 7 National Agricultural Research Institutes that conduct research of national strategic importance and 9 Zonal Agricultural Research and Development Institutes conducting adaptive research in the nine agro-ecological zones of Uganda (Uganda, National Agricultural Research Organisation 2024b).

NARO has conducted numerous research efforts, including developing crop varieties, such as maize, rice, and sorghum, resistant to pests and drought. In March 2024, an anti-tick vaccine was developed by NARO, in partnership with the Health and Biotechnology Research Group of the Institute for Game and Wildlife Research in Spain, to reduce the country's dependency on chemical acaricide pesticides that are associated with the progressive development of global acaricide-resistant tick populations. Moreover, anti-tick vaccines are cheaper, more effective, and environmentally sustainable (Uganda, National Agricultural Research Organisation 2024a, 2024c).

Science, Technology, and Innovation Secretariat at the Office of the President

The institution was first established in 2016 as the Ministry of Science, Technology, and Innovation (MOSTI) and later transferred to the Office of the President, which showed that STI is key to the country's socioeconomic transformation. The institution was then renamed the Science, Technology, and Innovation Secretariat at the Office of the President (STI-OP), and continued to be led by the minister of STI (Malabo Montpellier Panel 2024). The Secretariat develops policies, plans, and programs related to STI and supports public–private partnerships for investment in the sector. It implements its objectives through agencies such as the Uganda National Council of Science and Technology (UNCST), Uganda Industrial Research Institute (UIRI), the Banana Industrial Research and Development Center (BIRDC), and Kiira Motors Corporation (Malabo Montpellier Panel 2024).

UNCST is mandated to advise, develop, and implement policies and strategies for integrating science, technology, and research development in Uganda. Through UNCST, the government of Uganda awards grants, such as the Science Granting Councils Initiative (SGCI) II (2018–2023), to public and private sector research institutions to support technological and food product development innovations for improved food security (UNCST 2023; 2024).

UIRI focuses on "establishing platforms for value addition, product development, process design, sourcing technologies, machinery fabrication, processing plant management, small and medium enterprise (SME) outreach services, and business incubation" (UIRI, 2023a). The institute, recognized as a Center of Excellence for the East African community, conducts R&D in partnership with the public and private sectors, including universities and SMEs, and the outputs are translated into practical applications for food and nutritional security. UIRI's outstanding research has yielded awards such as a United Nations award for the portable electrochemical aflatoxin B1 kit and an innovation award for an electronically controlled gravity feed infusion set (UIRI 2023a, 2023b).

BIRDC was first established as the Presidential Initiative on Banana Industrial Development in 2005 to commercialize value-added banana products for export promotion. It ensures quality production of both raw material and processed products by addressing capacity-building and research needs for farmers and processors. Some key focus areas at BIRDC include value addition, quality control, food product development, marketing, soil management, and environmental impact assessment. BIRDC also trains farmers on improved banana production and processing methods and is also establishing community processing centers with dryers fueled by biomass-generated gas. Examples of successful value-added products are Raw Tooke Flour and Instant Tooke Flour (PIBID 2024).

STI-OP, which is mandated to support scientific innovations across prioritized industrial value chains to increase productivity, import substitution, and export of knowledge-based products and services, offers grants for R&D and innovations (process, products, technology, or business models). The grants awarded are based on themes/bureaus, and those related to bioeconomy development include (GCIC 2022):

- *Export promotion*: value addition to crops such as banana plants, Irish and sweet potatoes, cassava, shea butter, coffee, tea, mulberry trees, and mushrooms
- *Productivity acceleration*: value addition to fish as well as local production of concentrates for animal feeds, organic pesticides, and fertilizers; feed materials for black soldier fly larvae; eco-friendly multipurpose mobile farm tools (for ploughing, harvesting, threshing, weeding, juicing, etc.), and low-cost irrigation systems
- *Import substitution*: value addition to eggs, substitutes for wheat, organic cosmetics, and innovations in alternative soap manufacturing processes and inputs
- *Infrastructure innovations:* locally manufactured renewable energy production system, beneficiation of mineral ores, and innovative eco-friendly office spaces
- *Pathogen economy:* innovations to control crop pests and diseases, and modeling and sentinel surveillance tools for disease tracking in Uganda
- *Industry 4.0+*: educational platforms for STI mentorship and training; and artificial intelligence/internet of things applications for manufacturing, health, agriculture, energy systems, and similar

Government Research and Innovation Fund to Public Universities

One of the key areas of focus in the Uganda Vision 2040 is advancing in STI, engineering, and human resource development (Uganda, National Planning Authority 2024). To achieve this, the government set up the Research and Innovation Fund (RIF) in 2019 aimed at increasing the generation of translatable research and scalable innovations to address key gaps required for Uganda's economic development (Ninsiima 2020).

Makerere University was the first recipient of the funding in 2019/20. As of 2022/23, the government had awarded the university 105.5 billion Ugandan shillings (USh), equivalent to approximately US$29 million, which funded a total of 1,028 projects across all sectors critical for development. The university will receive USh25 billion (US$6.8 million) for 2023/24 to address 14 key research themes including "transforming the agricultural sector to drive development, works, manufacturing, science, and technology as tools to accelerate development, and energy and minerals as drivers of rapid economic development" (Makerere University 2023).

Other public universities have since benefited from the RIF, including Lira University, Soroti University, Mbarara University of Science and Technology, and Busitema University. The 2022/23 Busitema University's RIF grant of USh1 billion (US$272,000) focused on supporting 30 projects under themes such as appropriate technologies and clean energy; environmental sustainability and climate risk management; science, technology, engineering, and mathematics; and wealth creation through agriculture and animal production (Busitema University 2022). Lira University, which received its first round of RIF (2023/24) of USh500 million (US$136,000), will support funding in themes such as food and nutrition security and sustainable agriculture, climate change, and biotechnology (Lira University 2024).

Governance Structures: Policies

Uganda's policy landscape has set the stage for a comprehensive bioeconomy approach. The country has thereby focused its bioeconomy development on the energy and agricultural sectors, which are underpinned by environmental and sustainability conditions. In addition, in 2020, a comprehensive policy was drafted by MOSTI. The shared sustainability ambitions anchored in the policies provide a framework for implementing Uganda's bioeconomy ambitions while providing a foundation for cross-sectoral and cross-ministerial collaboration.

Biomass Energy Strategy

Biomass provides more than 90 percent of nationally consumed energy, with the rest split between electrical generation (mostly hydro) and imported fuel used for transport. The Biomass Energy Strategy was developed to manage biomass energy resources under the leadership of the Ministry of Energy and Mineral Development (MEMD). The strategy provides interventions to address challenges in the country's biomass sector, such as the high demand for biomass versus available supply. Given the country's potential to use biomass sustainably, applying the right technological interventions can prevent supply-side and demand-side wastage, resulting in a biomass surplus in the country. To harmonize the government's biomass information system, the strategy supported the creation of an interlinked biomass resource database and information center in 2016/17, with representatives from key government agencies such as the National Forest Authority and Uganda Bureau of Statistics (Uganda, Ministry of Energy and Mineral Development 2018b; Muthui and Nuwakora 2019; Uganda, National Forestry Authority 2024).

The strategy recommends approaches for achieving biomass supply across sectors, including scaling up and promoting multipurpose shrubs and trees, introducing appropriate technologies to utilize inferior forms of biomass, and introducing efficient wood-to-charcoal transformation technologies. The strategy encourages the production of improved biomass energy technologies (cookstoves and fuels) for fuel efficiency and clean cooking, which can employ youth and women as well as reduce the demand for charcoal and hence use less wood for charcoal production. Additionally, the strategy promotes the use of biogas, especially in institutions and cattle-keeping areas, which at the same time improves agricultural production by using slurry as high-quality fertilizer and also increases the use of liquefied petroleum gas by providing better distribution mechanisms and access to appliances through a credit scheme (Uganda, Ministry of Energy and Mineral Development 2018b).

National Biodiversity Strategy and Action Plan II

The vision of Uganda's NBSAP II is "to maintain a rich biodiversity benefiting the present and future generations for socioeconomic development" (NBSAP II). NBSAP II, implemented by the National Environment Management Authority (NEMA), was designed to build on NBSAP I (2002–2015). Some of the obstacles faced under NBSAP I included inadequate finances to implement planned activities, inadequate human and infrastructure capacity in the National Gene Bank, lack of a clearinghouse mechanism (CHM) to facilitate information sharing among institutions involved in biodiversity conservation, and inadequate management and technical capacity for implementation of NBSAP I at various government levels. These challenges have since been overcome. For example, capacity at district and local government levels to handle biodiversity conservation issues has increased, the CHM has been established, and innovative measures to increase funding have been put in place under the NBSAP II (Uganda, National Environment Management Authority 2016). NBSAP II (2015–2025) supports the development of a bioeconomy by addressing the unsustainable use of biodiversity resources to avoid a decline in the abundance of species due to overharvesting and exploitation of biological resources, including trees and biomass (Uganda, National Environment Management Authority 2016).

Uganda Green Growth Development Strategy

The Uganda Green Growth Development Strategy (UGGDS) 2017/18–2029/30 was developed to accelerate the implementation of the SDGs and the Uganda Vision 2040. The strategy aims to provide guidance on priorities, strategies, and governance frameworks for implementing green growth principles for the country's sustainable development. The UGGDS seeks to promote income and livelihood enhancement, increase the number of decent green jobs, and contribute to climate change mitigation and adaptation, food and nutrition security, environment and natural resources management, efficient resource use, social inclusiveness, and economic transformation at the national and subnational levels. Some of the priority areas for the implementation of the UGDDS' goals and objectives include (Uganda, National Planning Authority 2017):

- *Sustainable agriculture production and value chains* through increased access to irrigation facilities for at least 60 percent of smallholder farmers by 2030, integrated soil fertility management for all farming systems in the country, and upgraded value chains for strategic enterprises with a focus on product quality and quantity, market diversification, excellence in agro-processing, and effective use of knowledge acquired from within the value chain
- *Energy for green growth* through increased focus on renewable energy investments to use biomass energy for electricity through cogeneration by sugar companies and other modern technology options by 2030; development of improved energy-efficient biomass technologies for enhanced household cooking and industrial usage by 2020; enhancement of solar power potential and exploitation of geothermal energy; and support for development and/or reinforcement of environmental, health, and economic safeguards for energy generation in the country

Other priorities include the planning of green cities through comprehensive economic and physical planning, efficient waste management, sustainable transport, and natural capital management and development, including sustainable wetland and forest management (Malabo Montpellier Panel 2022). The UGGDS, therefore, contributes to the nation's efforts to develop a bioeconomy given its priority areas, which facilitate the sustainable transformation of agrifood systems and increased food security using biological resources, processes, and innovations while also supporting the development of a green economy (FAO 2022).

National Intellectual Property Policy

Uganda's National Intellectual Property (IP) Policy of 2019 aims to establish a suitable IP infrastructure that fosters innovation and creativity, builds human capital for the IP value chain, and improves the use of IP systems. The policy promotes the creation of a framework to safeguard traditional knowledge (TK) and traditional cultural expressions (TCEs), as well as the establishment of a digital database for TK and TCEs to protect cultural heritage from unauthorized use. Additionally, the policy facilitates better coordination among institutions, community organizations, and individuals who possess Indigenous knowledge. The development of a National Intellectual Property-Related Traditional Knowledge Action Plan, led by the Uganda Registration Services Bureau, is one of the initiatives to enhance the protection of traditional knowledge (Malabo Montpellier Panel 2022).

Biofuels Act

Uganda's Renewable Energy Policy (2007–2017) and the Biomass Energy Strategy (2018) laid the groundwork for the Biofuels Act of 2018 by legalizing the importance of sustainable production and utilization of biofuels. The Biofuels Act was passed to regulate biofuel production, storage and transportation, and blending of biofuels with petroleum products. The Act regulates the licensing of these biofuel activities and provides for the functions of the implementation ministry as well as offenses and penalties. MEMD works in partnership with other institutions to effectively implement the Act. For example, before the production of biofuels, MAAIF ensures that biofuel production does not negatively affect Uganda's food security and that the feedstock used for production adapts to Uganda's ecosystem. The operationalization of the Biofuels Act is currently in advanced stages ((Uganda, Ministry of Energy and Mineral Development 2018a; Mufumba 2022).

National Bioeconomy Policy Draft

Created by MOSTI in 2020, Uganda's National Bioeconomy Policy (2020) aims to boost bioscience innovation to enhance food security, improve health and nutrition, and generate jobs by expanding and intensifying sustainable bioresource production. It also seeks to translate bioscience research and innovations into industrial and commercial ventures by encouraging greater private sector involvement, ultimately transforming Uganda into a knowledge-driven economy (Malabo Montpellier Panel 2022). Thus, the policy promotes manufacturing high-value bioproducts such as biopharmaceuticals and vaccines, enhancing agricultural output and productivity, tackling climate change and its related impacts, producing biofuels, and effectively managing industrial and municipal waste (NaCRRI 2024). These objectives were established through extensive consultations with various stakeholders, including government and private sector representatives, academia, research institutions, donors, investors, civil society organizations, and umbrella associations. The policy outlines an institutional framework that addresses legal and regulatory needs to capitalize on the benefits of a successful bioeconomy. Once adopted, MOSTI will implement the policy in accordance with the East Africa Regional Bioeconomy Strategy established by the East African Science and Technology Commission. MOSTI will also oversee stakeholder engagement, coordination, and resource mobilization to foster a thriving bioeconomy (Malabo Montpellier Panel 2022).

Energy Policy for Uganda

The Energy Policy for Uganda (2023) builds on the first Energy Policy (2002). The vision of the Energy Policy for Uganda 2023 is to achieve universal access to sustainable, affordable, and quality energy services for all Ugandans by 2040, and the mission is to ensure reliable, equitable, efficient, and environmentally sustainable development, management, and utilization of energy resources and services. The Policy complements numerous subsectoral policies, such as the Renewable Energy Policy (2007–2017) and the Electricity Connections Policy (2018). The implementation of the policy will contribute to improved food security and sustainable agriculture, environmental conservation, and increased energy consumption per capita, among other goals (Uganda, Ministry of Energy and Mineral Development 2023). Policy targets include increasing the proportion of the population using clean cooking fuels and technologies from less than 15 percent to 50 percent and of households with at least one source of clean and modern energy from 51 percent to 100 percent; increasing energy consumption from renewable energy sources from 92.5 percent to more than 95 percent; and reducing carbon dioxide emissions from energy activities from 7.77 to 13.1 metric tons of carbon dioxide equivalent (Uganda, Ministry of Energy and Mineral Development 2023). Moreover, the government plans to invest in bioconversion technologies to unlock the potential for abundantly available biomass, animal waste, and municipal waste using more efficient technologies to maximize energy recovery. The policy also promotes the use of liquefied petroleum gas for cooking, sustainable utilization of biomass, adoption of energy efficiency and conservation practices in all economic sectors, enhancement of energy sector governance, capacity building and integrated planning, and climate change mitigation, among other goals (Uganda, Ministry of Energy and Mineral Development 2023).

Uganda Energy Transition Plan

The 2023 Energy Transition Plan (ETP) was developed by MEMD, with support from the International Energy Agency. Uganda plans to reach net zero emissions in its energy sector by 2065 and is, therefore, taking strategic actions to mitigate rising emissions by targeting sustainable approaches for economic development and ensuring growth in clean energy supply chains. The ETP is a strategic roadmap for developing and modernizing Uganda's energy sector and provides a pathway to achieving universal access to modern energy and sustainably powering the country's economic transformation. Although most households use solid biofuels such as charcoal and wood, access to clean cooking has increased from 0 percent in 2010 to approximately 15 percent in 2022. Notably, the majority of the population with access to clean cooking use improved biomass cookstoves, which burn biomass more efficiently. Uganda focuses on strengthening public–private partnerships for investments to achieve the objectives of the ETP, such as ensuring universal access to electricity and cleaner cooking by 2030 and providing a secure and affordable energy supply (IEA 2023).

Partnerships Between the Public and Private Sectors and Research Organizations

Science Granting Councils Initiative II: Public-Private Partnerships in Research and Innovation in the Manufacturing Sector

Science Granting Councils Initiative (SGCI) aims to strengthen STI research management, private sector engagement, and partnerships between SGCs and other science system actors. The first phase of the five-year Initiative (SGCI-I) was launched in 2015 as a partnership of the UK's Foreign, Commonwealth, and Development Office; Canada's International Development Research Center; and South Africa's National Research Foundation. SGCI-I included 15 countries, which have since increased to 17 in SGCI-II (SGCI 2024).

In Uganda, SGCI is implemented by UNCST under STI-OP. More than half of the 13 public–private partnership projects funded under SGCI-I in Uganda were related to the bioeconomy, with themes such as agro-processing and renewable energy innovations (Khaemba 2018; SGCI 2024). SGCI-II, titled Public–Private Partnerships in Research and Innovation in the Manufacturing Sector, awarded funding to six projects by public and private research institutions, which are all contributing to the advancement of Uganda's bioeconomy as listed below (Siyasa 2023; UNCST 2023):

- *Food Waste-2-Cricket Feed, a project of the Uganda Christian University (private) and PKM Reliable Enterprises Limited, aims to develop low-cost protein and micronutrient-rich cricket feed from food waste to facilitate the commercial production of crickets and* turn the insects into a nutritious food supplement
- Identification of standards and gaps in the bakery and confectionery industries—*a project of* the Department of Food Technology and Nutrition under Makerere University's CAES, the Uganda National Bureau of Standards, and several private sector partners—provides training on national food quality and safety standards for baked products
- Development of safe mass-rearing tools and value addition for the desert locust (Schistocerca gregaria Forskål) value chain in East Africa, led by Makerere University's Department of Food Technology and Nutrition and other regional researchers
- Upscaling the uptake of innovative technologies for increased value through the cocoa primary processing value chain, led by NARO
- Commercialization of propolis powder and infused tea bag for improved health and incomes in Ugandans, led by Makerere University's College of Veterinary Medicine, Animal Resources, and Bio-security and the Uganda National Apiculture Development Organisation
- Fractionation of Ugandan shea butter into commercial shea stearin and shea olein for industrial food and cosmetic application, led by the Natural Chemotherapeutics Research Institute

Running Out of Trees Campaign

To increase nationwide forest cover, the government launched the five-year ROOTs campaign in 2020 to promote the private sector's commitment to restoring declining forest cover by planting 40 million trees—especially Indigenous species—annually. The 40 million target was to represent one tree per Ugandan. The campaign aims to fulfill the government's pledge made during the 2014 UNFCCC COP20 to restore 2.5 million hectares of degraded land by 2030 (Bonn Challenge) (FAO 2021).

At the start of the campaign, the government had only 5 partners, but the number has increased to more than 30 as of 2023, including companies, religious and traditional institutions, schools, government agencies, and development partners. Examples of private sector partners include Tree Adoption Uganda, Absa Bank Uganda, Roofings Group, and TotalEnergies Uganda, which already had an ongoing tree-planting program engaged in the preservation of 10,000 hectares of natural forests. The government institutions involved include the National Water and Sewerage Corporation and NARO (TotalEnergies Uganda 2023).

Investment in Uganda's Forestry: The Government of Uganda in Partnership With the EU, FAO, and World Bank

The government of Uganda, in partnership with FAO and the EU, implemented the Sawlog Production Grant Scheme (SPGS) in three phases between 2004 and 2021. By the end of the project, more than 80,000 hectares of forests had been planted by commercial and community planters (FAO 2021). Following the success of SPGS, in 2023, the EU committed €40 million to support the government of Uganda's efforts in restoring national forest cover. The five-year EU–Uganda Forest Partnership aims to support Uganda's sustainable contribution of forest resources to national economic growth as well as global efforts to address climate change and loss of biodiversity. The partnership is expected to result in increased inclusive investments and decent job opportunities in sustainable forest–based value chains and forestry, decreased deforestation and degradation of forests, and improved effectiveness in governance, protection, and management of forest resources. The funding will help Uganda achieve its national contribution target of 21 percent tree cover by 2030, enhance biodiversity conservation, and facilitate trade in sustainable value-added wood products, all of which are in line with the Uganda NBSAP 2015–2025 and the Restoration of the Environment and Natural Resource Action Plan 2021–2031 (EEAS 2024a, 2024b; Kazibwe 2024).

In 2020, Uganda also acquired US$148.2 million from the World Bank for the Investing in Forests and Protected Areas for Climate-Smart Development Project aimed at improving the sustainable management of forests and protected areas and enhancing benefits to forest-dependent communities (World Bank 2020). The project (2020–2027), which is co-funded by the government of Uganda (US$30 million), was launched in 2021 and has been implemented across 30 districts consisting of 28 Central Forest Reserves, 7 national parks, and 4 wildlife reserves. Implementing partners in Uganda include the Ministry of Water and Environment; the Ministry of Tourism, Wildlife, and Antiques; Uganda Wildlife Authority; National Forestry Authority; and Ministry of Finance, Planning, and Economic Development (Uganda, Ministry of Water and Environment 2022, 2024).

Sustainable and Clean Energy Use

Using energy-efficient stoves and technologies is vital to supporting the sustainable use of biomass in Uganda. The government partners with other institutions to support the transition to clean energy for bioeconomy development in the country, as reviewed below.

Center for Research in Energy and Energy Conservation is a not-for-profit organization founded in 2001 at Makerere University. The Center supports the transition from traditional forms of energy to sustainable and clean energy by conducting research, innovation, training, testing of renewable energy products, and consultancy in six thematic areas: rural electrification, energy for productive use, energy efficiency, household energy, energy entrepreneurship, and energy testing. The Center is accredited by the Ministry of Education and Sports to conduct competency-based training in renewable energy and energy efficiency. As of 2023, more than 600 entities have been trained at the Center, with activities including stove design and testing, biomass gasification (installation, maintenance, and repair of biogas equipment), solar installations, and hydropower design and installation training. In partnership with the government, the Center provides standards and quality assurance for renewable energy products such as improved stoves (CREEC 2024).

Uganda National Renewable Energy and Energy Efficiency Alliance, incorporated in 2015, is a nonprofit organization of six business associations and actors in the renewable energy and energy efficiency subsector. The Alliance represents private sector businesses and actors engaging in renewable energy and energy efficiency to the government by advocating for a conducive business environment for sustainable growth and development. Its members include BEETA (Biomass), HPAU (Hydro), WPAU (Wind), EEAU (Energy Efficiency), USEA (Solar), UNBA (Biogas), and ARUWE (Women Empowerment) (UNREEEA 2024).

Uganda National Alliance on Clean Cooking (UNACC) is a nonprofit organization established in 2013 to promote the adoption and utilization of clean cooking technologies and practices by bringing together all stakeholders. UNACC generates and disseminates knowledge on clean cooking technologies, policies, and best practices and engages with policymakers and stakeholders to develop, promote, and enforce standards and policies that encourage the adoption and scaling up of clean cooking solutions. To achieve its objectives, UNACC works in partnership with government institutions such as Uganda's Ministry of Water and Environment and MEMD, as well as with development partners such as The Netherlands Development Cooperation, GIZ, Modern Energy Cooking Services, and FAO (UNREEEA 2024).

Conclusion

The high dependency on biomass by Uganda's population has resulted in an urgent need for the formulation of numerous policies, strategies, and laws to achieve a bioeconomy in alignment with the national goals anchored in the Uganda Vision 2040 and NDPs, as well as with continental and global commitments such as the East Africa Regional Bioeconomy Strategy. In partnership with the private sector and development organizations, the government of Uganda has invested in and implemented several initiatives to restore forest cover and biodiversity to ensure the sustainable usage of biomass, which in turn mitigates climate change. For many decades, Uganda has aimed to increase the usage of clean and renewable energy by developing and implementing policies and strategies such as the Biomass Energy Strategy (2013) and the new Energy Policy of Uganda (2023). To promote clean and renewable energy usage, the government also partners with nonprofit organizations such as UNACC.

Successes recorded by Uganda also include the prioritization of the government to fund research and innovations in areas such as biotechnology, agro-processing, and clean energy technologies, which can be scaled up for adoption nationally. Other funding sources such as SGCI have supported research collaborations between public and private sectors by funding projects such as the Food Waste-2-Cricket Feed project. Uganda's bioeconomy is set to continue thriving with continued public–private sector investments and effective implementation of the developed policies. Moreover, over the next four years, the government plans to establish a biosciences park as a one-stop center for R&D. The park will host technological infrastructure such as research laboratories, technology development workshops, prototyping facilities, and testing and analytical facilities to enable the entire product and technology value chain to achieve final commercialization. This is set to strengthen the competitiveness and R&D of biobased SMEs and to help grow new biobased industries through scientific knowledge, technology transfer, and bio-incubation.

Country Analysis: Thailand

Introduction

Thailand initiated its discussion on bioeconomy internally about two decades ago. After several rounds of internal consultations among key stakeholders, well-defined bioeconomy national goals and a dedicated bioeconomy strategy, National Biotechnology Framework 2012–2021, were developed (Thailand, Ministry of Science and Technology 2012). The more recent Bio-Circular-Green (BCG) Economy Model and Action Plan 2021–2027 is an important national strategy focused on bioeconomy. The bioeconomy is expected to expand in the future to promote a green economy and address regional income disparities. The overall vision is "to create sustainable and quality growth with science, technology, and innovation, enabling higher income, a better quality of life, and a good balance of utilization and conservation of biological and natural resources" (Thailand, National Science and Technology Development Agency 2022). The FAO Bioeconomy dashboard has mapped the 42 actions included in Thailand's bioeconomy strategy, showing that 20 percent are in the health and pharmaceutical industry and 20 percent are in bioindustries in general (around 10 percent of these are in the food, feed, and beverages industry, and the other 10 percent are in the ecotourism sector). The rest are in the agricultural sector, ecosystem services, training and capacity building, and cross-sectoral activities. Half of the actions are contributing to climate change and biodiversity targets of the CBD and UNFCCC (FAO 2024a).

The Thailand Board of Investment is providing incentives to attract foreign investment for the BCG economy. At the regional level, the bioeconomy strategy of Thailand is driven by the Asia-Pacific Economic Cooperation (APEC) and

Association of Southeast Asian Nations (ASEAN) bioeconomy consultations and agreements. The larger goals of APEC, for example, include the Bangkok goals for the BCG economy that aim to bring together the objectives of inclusive and sustainable growth with technological innovations to create value in bioindustries, recycling to reduce waste and increase resource use efficiency, and the development of business environments (APEC 2022; Kumagai 2022). A recent study analyzed and compared the status of the bioeconomy concept in the Mekong region in three countries: Thailand, Vietnam, and Laos. It found that there is a need for a clearer bioeconomy vision, further research to understand the economic valuation of bioeconomy, and scope for greater involvement of stakeholders at the policy level (Rinn et al. 2024).The food and agriculture sector plays a critical role in the development and implementation of the strategy. Through application of biotechnology innovations, particularly in the cassava and sugarcane value chains, it promotes the bio-industrial complex (Lakapunrat and Thapa 2017). FAO has a project with ASEAN to build a community of bioeconomy experts in the region and advance the development of a shared and coherent concept of the bioeconomy, with Thailand being the main implementer (ASEAN Cassava Center 2024). In addition to the industrial approach to bioeconomy development, Thailand also intends to work at the community and landscape levels. This local strategy combines Indigenous knowledge, biodiversity conservation, and community-based business models to generate benefits for local economies by promoting BCG approaches and their implementation by the local governments (Aung, Nguyen, and Denduang 2020). The Master Plan for Integrated Biodiversity Management 2015–2021 emphasized the importance of traditional knowledge, innovations, and practices of Indigenous and local communities for the conservation and sustainable use of biodiversity. It aimed to fully integrate and reflect it in the implementation of the CBD with the full and effective participation of Indigenous and local communities, at all relevant levels (Thailand, Ministry of Natural Resources and Environment 2015). As a major player in the agricultural trade in the ASEAN region, Thailand uses value addition in agriculture as the key driver to knowledge-based bioeconomy development. This strategy combines the comparative advantage of crop production and identification of regional trade and business opportunities to effectively use its industrial and food processing infrastructure. Thus, Thailand balances internal strengths in the development of its bioeconomy with regional opportunities provided in the ASEAN region. The development of the bioeconomy in Thailand provides an illustrative case study for emulating its success elsewhere.

The ASEAN Action Plan for Sustainable Agriculture has been a driving force, tackling crucial issues such as decarbonization, reduction of harmful chemicals in farming, and the embracing of digitalization within the agricultural sector. Additionally, the plan prioritizes climate change adaptation and fosters public–private partnerships to ensure long-term sustainability. Complementing these efforts, the ASEAN Strategy for Carbon Neutrality, launched alongside the Action Plan, aims to accelerate a collaborative transition toward a green economy. This ambitious strategy encompasses 8 regional strategies and 16 specific initiatives, all designed to support national efforts and promote sustainable growth.

Governance Structures

Effective governance is recognized as central to the development of Thailand's bioeconomy. The development of the BCG model was led by the Ministry of Higher Education, Science, Research, and Innovation, but it cascades down and is applied by government agencies under different initiatives and projects. The government of Thailand identified the improvement of social inequality and sustainability as its core governance objectives in the context of bioeconomy development. The government, private sector, academic and research institutions, civil society, and international organizations are all involved in the bioeconomy sector. The public policies and strategies are developed and implemented in consultation with experts in the bioeconomy through a multistakeholder process.

For instance, the BCG Action Plan Implementation Committee is chaired by the minister of higher education, science, research, and innovation. The committee is responsible for implementing, tracking, and developing an enabling environment. Emphasizing the need for coordination, subcommittees are formed with experts from across the field. Along with agriculture, other sectors such as tourism, medical devices, drugs, and vaccines are included (Thailand, National Science and Technology and Development Agency 2021).

The National Center for Genetic Engineering and Biotechnology (BIOTEC), under the National Science and Technology Development Agency, is responsible for driving strategic initiatives to advance the country's bioeconomy agenda. It provides expertise and resources to formulate and implement policies that promote innovation, sustainability, and economic growth in Thailand's bioeconomy sector. Lastly, it supports prioritizing areas under agricultural biotechnology, aquaculture sustainability, biomedical research, environmental conservation, and bioenergy development (BIOTEC 2021).

Another key entity is the Ministry of Industry's Office of Industrial Economics, which develops bioeconomy policies and engages stakeholders (Aung 2021). Public sector STI systems work with the private sector to identify research priorities of the bioeconomy sector. The public extension system under the Ministry of Agriculture and Cooperatives disseminates technology to producers and processors, and the development of the value chain is undertaken through a process of public–private partnership. Rules and regulations are agreed upon among the stakeholders at each node of the value chain. The primary production systems adhere to a set of guidelines that provide for sustainable use of bioresources. The intermediary product producers abide by a set of prearranged standards and regulations. Thus, the development of the bioeconomy is governed by a set of regulations including tax and nontax incentives, exemptions, and price and environmental regulations (Kumagai 2022; OECD 2021).

Multistakeholder consultations and engagement with a wide range of stakeholders—from farmers to processors of raw materials along with investors and end users—facilitate an inclusive bioeconomy growth process in Thailand. Addressing the concerns and considering the perceptions of this wide range of actors helps the government to incorporate equity and sustainability considerations into the development process.

The governance of bioeconomy in Thailand also involves addressing multisectoral goals. While the agricultural sector is a prime actor in the development of the bioeconomy based on crops such as cassava and sugarcane, other sectors are also important, such as biodiversity, forestry, natural resources and environment, trade, and commerce. In addition, bringing together stakeholders from the research and innovation, business, investment, and trade sectors to develop guidelines and regulatory processes has helped to speed up the process of developing bioeconomy businesses. Continuous engagement of these stakeholders and providing accountability at all levels has been the hallmark of the governing process in the development of Thailand's bioeconomy.

The Office of the National Economic and Social Development Board administers the strategy's monitoring efforts. The Thailand Biodiversity-Based Economy Development Office also works on the bioeconomy. For instance, it is involved in the development of biodiversity impact standards for reporting and proxies for measuring impact, and it provides technical support for impact measurement (Aung, Nguyen, and Denduang 2020).

The Sustainable Consumption and Production Association Thailand (SCP) supports the implementation of the Thai SCP Roadmap 2017–2037. At the regional level, the United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP) promotes environmentally sustainable economic growth, or green growth, through its analysis, policy advocacy, capacity building, and technical assistance, in particular through the Seoul Initiative Network on Green Growth. UN-ESCAP's policy support for green growth and resource efficiency, including steps toward the establishment of an ASEAN Resource Panel, provide important perspectives to this joint initiative. The recently organized 11th Regional 3R and Circular Economy Forum in Asia and the Pacific brought together regional countries to review progress on the bioeconomy (FAO 2023b).

Policies and Tools for Facilitating Public–Private Partnerships

Thailand's government established a national version of public–private partnerships (also known in Thai as *pracharath*) to foster collaborative partnerships among government, business groups, academics, and research institutions to promote various development projects (Aung, Nguyen, and Denduang 2020). While the government holds the largest role in providing financing and improving the sustainable management of biodiversity in the country, leveraging public–private partnerships in mobilizing funds, increasing private investment, and employing blended financing are key to a thriving bioeconomy.

National Biotechnology Policy Framework

For the past two decades, a key policy guiding the process of Thailand's bioeconomy development has been the National Biotechnology Policy Framework (2012–2021) under the Ministry of Science and Technology. This policy framework showed the need for a knowledge-based and biotechnology-driven bioeconomy sector for Thailand. It brought together the potential application of biotechnology-related innovations and applications in a wide variety of sectors including agriculture, health, aquaculture, and other bioindustry sectors.

Alternative Energy and Development Plan and National Roadmap for the Development of Bioplastics Industry

The National Biotechnology Policy Framework was further supported by industry-specific roadmaps and strategies. For example, promoting biofuel and bioenergy in the renewable energy sector was guided by the Alternative Energy and Development Plan (2015) by the Ministry of Energy, and the development of the bioplastics industry is part of the Ministry of Science and Technology's National Roadmap for the Development of Bioplastics Industry (2008). These policies are further integrated with the broad development perspectives that promote knowledge-based, technology-driven policies (IACGB 2020).

Thai Industrial Development Strategy 4.0 (2017–2036) and 20-Year National Strategy

The Thai government wants to drive the country to "Thailand 4.0," which focuses on sustainable development and growth. As part of this effort, the biofuel and biochemical industry has been identified as important for steering economywide progress (Ministry of Industry 2016, 2018). The 20-year national strategy (2018–2037) has a strategic focus on expanding high-value bioindustries.

The Cane and Sugar Act, B.E. 2565

Within the agriculture and biotechnology industry, sugarcane is considered an important commodity from a bioeconomy perspective. The Cane and Sugar Act, B.E. 2565 (2022), promotes the cane and sugar industry's production of value-added products such as ethanol, biomass, and other products.

Bio Hub Asia

The Ministry of Industry created the Measures for the Development of Bio Industry in Thailand 2018–2027 to promote Thailand as a biotechnology hub of ASEAN. The focus is on three target products comprising bioplastics, biochemicals, and biopharmaceuticals (Thailand, Ministry of Industry 2019). Bio Hub Asia is being developed in cooperation with the Eastern Economic Corridor committee and the Board of Investment of Thailand. By providing tax breaks and other incentives including exemptions or reductions from import duties, it focuses on more than 50 bio-related factories such as chemicals, refineries, pharmaceuticals, and medicine and health (Bio Hub Asia 2024).

The Bio-Circular-Green (BCG) Economy Action Plan

The BCG Action Plan (2021–2027) was formulated to leverage Thailand's comparative advantage in biological and cultural diversity to drive sustainable development and self-reliance. The plan employs multistakeholder engagement involving the government, industry, academia, and civil society and highlights the need for an investment-driven approach. From the bioeconomy perspective, it aims to create value through efficient conservation, management, and utilization of bioresources. The plan's strategic focus areas include agriculture and food; health and wellness; energy, material, and biochemicals; tourism and the creative economy; and circular economy. It also addresses the need to enhance individual skills on relevant topics such as quality assurance and control, resource management, and business and technology skills (Johnson et al. 2022; Thailand, National Science and Technology and Development Agency 2021). The BCG Policy Board led by the prime minister serves to drive the policy and is responsible for mobilizing investments and resources for bioeconomy initiatives. The plan's implementation will be monitored through an electronic system (Thailand, National Science and Technology and Development Agency 2021).

Public, Private, and Research Sectors

In Thailand, the development of the bioeconomy engages several actors and players who come together to form a web of interlinkages. As individual entities, none of these players can advance the process of bioeconomy transformation. For example, the government needs investors to make their policies and strategies a reality. Private investors, on the other hand, need to work with the banking sector to have sustainable financing of their projects. The policy and governance framework that Thailand follows ensures all relevant entities participate and work together smoothly to produce the desired outputs. The public–private partnerships developed for each of the value chains support the joint innovations that produce economic benefits for society. The regulatory systems developed through the governance framework also support public–private partnerships in research and innovation (Kumagai 2022; Thailand Board of Investment 2019). There is potential for developing strong synergies between foundations or investment funds and government programs to promote the bioeconomy (UNDP 2020).

Sugarcane as a source of biofuel and bioenergy illustrates the development of a bioeconomy that brings together government, private, and other entities. It is an ideal bioeconomy crop to produce multiple value-added biofuels and biochemical products. Sugarcane processing also produces by-products that could be used in bioethanol production. Sugarcane milling accounts for 30 percent of ethanol produced in Thailand (Manivong and Bourgois 2017). Sugarcane farmers are the primary producers and benefit from the support of the government extension agents, who in turn receive their knowledge from the innovation sector supporting both public and private investments. Millers buy sugarcane from farmers and produce sugar and its by-products. Other sugarcane processors also play an important role in processing and distributing sugar and its by-products.

These actors are guided by the Office of the Cane and Sugar Board, which sets priorities for research, regulations, and technology standards. Although progress has been made, new challenges continue to emerge in the sugarcane bioeconomy.

The importance of cassava as a global bioeconomy crop has gained momentum recently (Ogwu et al. 2024). It is used as raw material in many industries and for human consumption and animal feed. However, cassava mosaic disease poses a threat to the overall yield and quality. To address this problem, BIOTEC has developed diagnostic tests, including an enzyme-linked immunosorbent assay and an immunochromatographic strip test. The technology is relatively new, and there is significant scope for wider adoption and capacity building (Thailand, National Science and Technology and Development Agency 2023). New agricultural practices and technologies such as tissue culture and mini-stem cutting techniques can also be considered for cultivating disease-free cassava plants but would require investment and training support.

Conclusion

Thailand's efforts to develop its bioeconomy present several lessons for countries that may try to emulate its process and success. First, the government of Thailand firmly believes that the bioeconomy holds potential to combine production and conversion of natural and bioresources in a sustainable manner that can enhance the livelihoods of the people who depend on it, reduce social inequality, and overcome the middle-income trap. Second, it has integrated bioeconomy strategies into larger socioeconomic development plans and attempts to effectively use bioscience, biotechnology, and technological innovation to drive business development. Third, bringing together science and technology development, business models, and markets for bioproducts and their by-products through increased funding, regulatory frameworks, and collective governance can have a high payoff. Finally, this case study demonstrates the importance of continuous updating among stakeholders and shows that addressing the knowledge gap is key to increasing the competitiveness of Thailand's bioeconomy.

Country Analysis: Brazil

Introduction

Shaped by its economic constraints and geographical conditions, Brazil opted to adopt a bioeconomy approach for its economic development several decades ago and has been a leader in this field since. Following global trends, it has taken on several broad strategic streams in developing its bioeconomy: reducing dependency on fossil fuels, adding value to primary products, recycling biowastes, and developing innovative bioproducts such as biofertilizers, bio inputs, and bioethanol production. These strategic streams are complemented by the development of new productive systems and business models driven by a governance structure that coordinates academic research, a business council, agribusiness, global cooperation structures, and a supportive policy system. On World Environment Day, June 5, 2024, Brazil launched its national holistic bioeconomy strategy. The bioeconomy is considered to be a model of productive economic development that is (1) based on values of justice, ethics, and inclusion; (2) capable of generating products, processes, and services efficiently; (3) based on the sustainable use, regeneration, and conservation of biodiversity; (4) guided by scientific and traditional knowledge and its innovations and technologies; and (5) designed to add value and generate work and income, sustainability, and climate balance. The social aspects therefore play a crucial role in the design of its bioeconomy policy. For instance, one of the objectives is "to promote forest and socio-biodiversity economies, based on the identification, innovation, and enhancement of their socioeconomic, environmental, and cultural potential, with the expansion of participation in markets and the income of Indigenous peoples, traditional communities, and family farmers" (Brazil, Acts of the Executive Branch 2024).

At the same time, Brazil has developed strategic partnerships and alliances with countries that have shown ambition in developing their bioeconomies. For example, it joined the global collective effort with 20 countries to speed up the process of developing and using biofuels as an alternative source of energy. In the Latin American and Caribbean (LAC) regional context, Brazil developed a partnership with Europe to promote a knowledge-based bioeconomy that helps nurture strategic alliances between LAC and Europe in bioeconomy policy development. It has also partnered with countries that are part of the Overseas Countries and Territories Association and FAO to support the advancement of bioeconomy in all Amazonian countries. Currently, Brazil is leading the G20 Initiative on Bioeconomy as the Chair of G20 for 2024. In this role, it is developing strategic approaches to improve the competitiveness of the national bioeconomy in member countries. Such partnerships and alliances have been the cornerstone of developing Brazil's bioeconomy strategy for the past two decades. This case study elaborates on the policy, institutional, and governance drivers of bioeconomy development in Brazil.

Governance Structures

The overall mission of the Brazilian bioeconomy model is driven by its unique organizational structure and governance framework. This framework revolves around articulating bioeconomy activities that have a high potential to contribute to economic development. A set of organizations that participate in the bioeconomy growth process have jointly set priorities for bioeconomy interventions and articulate policies and strategies that support such interventions. The strategy was signed on June 5, 2024, by the president of Brazil; the minister of environment and climate change, who will be in charge of monitoring and knowledge sharing; the minister of development, industry, trade, and services; and the minister of finance. The strategy will be also implemented by the different regions, municipalities, civil society organizations, and the private sector.

In the context of the agriculture sector, a wide range of stakeholders—including the Ministry of Agriculture, Livestock, and Food Supply (MAPA); the Brazilian Agricultural Research Corporation (EMBRAPA), which is the research and innovation system for Brazilian agriculture; the private sector, which drives the value chains; state-level ministries of agriculture and their research and extension system; and farmer organizations that produce bioproducts such as sugarcane—come together to decide on the policy priorities, institutional strategies, and investment priorities to drive the bioeconomy. MAPA and the Ministry of Science, Technology, and Innovation (STI) are key ministries to develop and monitor the policy and regulatory systems.

The Ministry of Environment and Climate Change is in charge of a National System of Information and Knowledge on the Bioeconomy, responsible for collecting, processing, and storing information on the performance of the bioeconomy.

A key aspect of Brazil's bioeconomy governance framework is the coordination of the vision, mission, and objectives of bioeconomy participants, ranging from smallholder farmers, local buyers and aggregators, processing industries, commercial traders, and final users. In addition, by working with knowledge producers and innovators like EMBRAPA, the private sector, and state departments of agriculture to guide the process of bioeconomy-related innovations and technologies, the governance framework helps to accelerate the process of research and innovation. Collectively, the entities involved in the bioeconomy landscape work together to improve their interactions to achieve needed productivity gains and competitiveness in the Brazilian bioeconomy.

In the context of specific sectoral approaches, the food–water–energy nexus plays a leading role in Brazil's bioeconomy development. For example, the Action Plan on STI in Bioeconomy has primarily helped advance the coordination of bioeconomy interventions that support the development of economic activities. Such coordination helps identify opportunities for value addition through biotechnological processes and the effective and sustainable use of biomass.

The governance mechanisms guiding the ethanol production system are one example of translating national policies into state-level action. While national-level research and innovation outcomes in the agriculture and livestock sector are supported by EMBRAPA, the leading publicly funded national research organization, they are then translated into state-level interventions by the states and through their respective extension systems. These innovations and potential bioeconomy interventions are further disseminated through local administrations at the municipality level and by the private sector. The production and buying back arrangements are made through private companies that contract with farmers for their bioproducts (sugarcane and its by-products, for example). Local extension systems support farmers in designing production systems and input supply. They further act as brokers between farmers and processing industries that focus on bioenergy and biofuel development from sugarcane (EMBRAPA 2024).

Policies and Tools for Facilitating Public–Private Partnerships

Bioeconomy development in Brazil is highly integrated with its political economy. For example, the Brazilian economy is highly dependent on its natural resources, particularly the rainforests. The preservation and management of the resources stemming from the rainforests must be a key policy objective of the Brazilian government, and any policy changes can have huge implications for the development of the bioeconomy. The plans of the current government headed by President da Silva aim to eliminate deforestation by 2030 (G20 2024a).

Until recently, Brazil had several broad policy initiatives that addressed the emerging needs of the bioeconomy industry. These policies included the Plano Decenal de Expansao de Energia 2031 which addressed bioenergy policy needs; the Action Plan on STI in Bioeconomy; National Strategy on STI 2016; and the Biotechnology Strategy (2007). The 2024 national bioeconomy strategy presents an important integrated vision for nurturing bioeconomy industries through a National Bioeconomy Development Plan, which will establish the resources, actions, responsibilities, goals, and indicators for bioeconomy development, in accordance with policies and sectoral plans. The plan will be prepared in accordance with policies on environmental protection, industrial development, STI, agriculture and family farming, biodiversity and access to genetic heritage, regional development, and sustainable development of traditional communities, among others (IACGB, 2024; Brazil, Acts of the Executive Branch, 2024).

The National Strategy for STI, introduced in 2016, provided a broad set of guidelines for the development of projects in bioeconomy sectors that promoted science and innovation. This strategy was further reinforced by the bioeconomy-specific action plan in 2018 that helped to initiate institutional mechanisms for the implementation and operationalization of bioeconomy industrial projects. It gives the overarching framework for integrating bioeconomy subsectors such as agriculture, forestry, biodiversity, sustainability, environmental protection, and others. Sustainable production, processing, and value addition to biomass through the development of innovative products are the action plan's key strategic objectives. The action plan was also helpful in aligning global and regional needs for bioeconomy development to the Brazilian projects and identifying critical knowledge gaps (Brazil, Ministry of STI 2016, 2018). The Observatory of Knowledge and Innovation in Bioeconomy is an interdisciplinary center created by the Getulio Vargas Foundation (FGV), specializing in climate change, land use, and biodiversity. FGV's Bioeconomy Observatory monitors advances in the regional bioeconomy and investigates ways to reconcile income and wealth generation with the preservation of the forest and its biodiversity (FGV 2021). The observatory conducted a study on the main sources of methane emissions per sector in Brazil (FGV 2022).

In developing bioeconomy strategies and action plans, the Brazilian government has been concerned with issues related to equity and biodiversity. Policies thus focused specifically on smallholder farmers and on traditional and Indigenous communities, as they remain major custodians of biodiversity. For example, the socio-biodiversity program developed by the Ministry of Agriculture in 2019 aims at creating sustainable partnerships between the government and farmers, Indigenous groups, and their businesses. A key expected outcome is the sustainable use of biodiversity resources for the economic benefits achieved through context-specific approaches that combine livelihood development and biodiversity goals (FAO 2020).

The role of public and private actors and players in the development of the bioeconomy can be best illustrated by the forestry sector. Brazil's forest area is the second largest in the world, covering 496 million hectares. However, close to 80 percent of the wood used in the biological processing and wood industry originates from planted forests and is run and operated by the forest industry. Planted forests play a key role in the development of the bioeconomy in Brazil. The wood industry value chains added an average of 1 percent to the GDP between 2010 and 2020 and created more than 1.5 million direct and indirect jobs for the local population in 2020. Pulp, panels, and paper products dominate the industry, making Brazil the world's second-largest pulp producer (IBA 2021; Maximo et al. 2022;).

The development of the bioeconomy policy and strategy and the organized approach to the development of the bioeconomy sector in Brazil directly influences the role of the forest wood industry in its bioeconomy. Innovations driven by a bioeconomy approach to the forest sector development contribute to the identification of economic opportunities. Science and technology policies guide the process of investments in research from both public and private sectors, which translate into the application of biotechnology to the development of new technologies, biological processes, and innovative products from the forestry sector. In addition, the Brazilian bioeconomy strategy also complies with national regulatory norms and international commitments such as UNFCCC.

The development of a bioeconomy in one of the poorest states in Brazil provides an example of how a bioeconomy plan can be developed and benefit the smallholder sector. The State of Pará is at a crossroads in its struggle between the exploitation of the Amazonian forests by cattle ranchers and deforestation activities and the sustainable use of natural resources through careful nurturing of a bioproduct industry that can benefit the custodians of forest resources. According to World Bio Market Insights (2023), the state has developed a strategy, PlanBio, that provides impetus to a nascent bioeconomy industrial complex (Brazil, State of Pará 2022). Its PlanBio was unveiled at the UNFCCC's COP27 in December 2022. The implementation program has a projected budget of US$232 million for the next five years. The plan aims to support Indigenous, quilombola, and traditional communities by (1) strengthening capacity for genetic heritage and traditional knowledge, (2) strengthening managerial capacity, and (3) establishing a permanent dialogue between the state and these communities. The plan's key objective is to develop a bioeconomy system that benefits small-scale farmers through the sustainable use of bioproducts from the Amazon rainforests, which continue to face the highest rates of deforestation from ranching operations. The implementation of PlanBio as a strategy to serve the smallholder sector and reduce the exploitation of forests through sustainable resource use can be illustrated by one bioproduct: Acai, a biobased product extracted from the trees of the Amazon rainforest, is in high demand from the health food industry. However, organizing the smallholder sector to produce bioproducts based on acai and ensuring a larger share of the marketed value remains with them requires an organized approach to developing the bioeconomy around each of the potential products. Major aspects of such an approach involve creating a platform to bring together smallholder producers in work; supporting them with technologies and innovation that will help identify new product lines; connecting them to the right market opportunities both within Brazil and outside the country; and providing credit for their operations, including producing these bioproducts and processing them for specific market needs. To increase financial access to producers, PlanBio has promoted its own credit operation in the form of a regional bank called Banpará. This state-owned regional bank facilitates credit to primary producers as well as owners of processing units. These credit lines are important for the processors of acai fruit, who convert the fruit into higher-value products to be used in health food industries.

The Amazon potentially has close to 1,000 bioproducts that could be economically used and exported. Only a minor share of these products is produced without deforestation. A major challenge in the current process of extracting and selling these resources is that only a small share of the value generated by these products reaches the smallholders who produce or harvest them—less than 0.20 percent of an estimated US$176 billion (World Bio Market Insights 2023).

The bioeconomy initiative in the G20 process, for which Brazil is the 2024 chair, illustrates Brazil's regional leadership in promoting the bioeconomy, highlighting emerging lessons for the development of the bioeconomy in other countries in the Global South (G20 2024b). While effective and sustainable use of bioresources is the driving principle, the bioeconomy's contributions to the social inclusion and livelihood goals of vulnerable populations and the attainment of the SDGs are given equal importance. In addition, investment in science and technology is key to the innovation process, but effective use of Indigenous knowledge is also relevant. Knowledge sharing is a critical process of South–South learning. The Brazilian approach to deriving economic benefits from genetic resources ensures the sustainable use and preservation of biodiversity, and that Indigenous populations receive an equitable share of the benefits from such resources.

The FAO dashboard shows that Brazil has several other policies and international agreements that explicitly include bioeconomy. The Sixth National Report to the CBD mentions bioeconomy as a means to support biodiversity together with supporting compensation for ecosystem services, formalizing land ownership, and the like. The bioeconomy is also mentioned in the National Pathway to Sustainable Food Systems, which proposes three action areas to advance the bioeconomy for food and agriculture (research and innovation on bio inputs and biofactories, empowerment of smallholders and involvement of Indigenous communities, and promotion of sustainable biodiversity use and equitable pricing for socio-biodiversity products). The UNFCC's COP30 in 2025 will be held in Belem, State of Pará, and the bioeconomy is likely to be a key part of it.

Conclusion

As the Brazilian case study illustrates, the development of a bioeconomy involves the effective use of a country's natural endowments through the confluence of several streams of interventions, including developing and nurturing policy-related, institutional, business, and research and innovation environments. Multiple sectors and multiple stakeholders participate, depending on their interests and the rewards they get from participation. While the government at the federal and regional levels develops policies and strategies that facilitate the research and innovation process, the private sector is incentivized to invest in technology development and the implementation of businesses that benefit the economy. Institutional mechanisms and regulatory processes are also an important part of providing incentives and ensuring societal goals of biodiversity, sustainability, and inclusivity. Cooperation across stakeholders in the development of the bioeconomy and the governance of these interactions between the government, private sector, farmers, NGOs, and development partners ensures the emergence of a sustainable bioeconomy. The international dimension is also very important for Brazil, including sustainable trade. Transforming innovations into business opportunities, ensuring that these businesses sustainably contribute to bioeconomy development ,and regulating potential conflicts among various actors and players to achieve the collective goals of bioeconomy policies are key to the success of Brazil's approach.

Conclusion and Key Findings From the Country-Level Analysis

The countries studied in this chapter are actively developing targeted policies and strategies to harness their natural resources sustainably, albeit with different entry points aligned with their unique environmental challenges and economic structures. All countries illustrate a comprehensive and strategic pursuit of bioeconomy development, emphasizing sustainability, innovation, and cross-sectoral collaboration.

In **Ghana**, the bioeconomy is seen as a vehicle for transforming and strengthening food systems and mitigating climate change. The country capitalizes on its rich biodiversity and biomass resources to foster economic growth, which includes developing sustainable biomanufacturing industries. STI plays a central role in Ghana's socioeconomic development and the development of its bioeconomy. This, in turn, provides a strong foundation for scaling up its emerging bioeconomy to other sectors.

Namibia is making strides in sustainable resource management, notably through its Bioeconomy Strategy 2023–2028, which sets out the country's ambitions to take a cross-sectoral and multistakeholder approach to roll out a vibrant bioeconomy. In particular, agrifood systems, tourism, waste management, and Indigenous knowledge systems are key areas of work. Export alignment with sustainable practices showcases Namibia's focus on leveraging its bioeconomy for development and export growth. Namibia's 2022–2027 National Strategy on Bush Resource Management underscores the importance of robust governance and comprehensive strategies to harness natural resources for economic gain while ensuring environmental sustainability. Bush control efforts promise strategic investments in biomass and renewable energy, which are vital for economic and ecological benefits and for enhancing bioeconomy prospects.

Uganda prioritizes advancing its bioeconomy through strategies and policies promoting clean, renewable energy and fostering public–private partnerships. These align with national and regional development objectives. Uganda demonstrates a commitment to sustainable bioresource use, leveraging biodiversity and biomass across sectors, and promoting low-carbon pathways toward a circular bioeconomy. Investments in the agriculture, energy, and health sectors, integrating technology and innovation, are significant. Institutions such as NARO and collaborations across sectors drive sustainable agriculture, energy solutions, and food security, highlighting Uganda's proactive stance in bioeconomy development.

For an additional perspective and bioeconomy pathways, this chapter also focused on the distinct approaches taken by the governments of Thailand and Brazil to transition to a bioeconomy.

Thailand, as a major player in the agricultural trade in the ASEAN region, uses value addition in agriculture as the key driver to developing a knowledge-based bioeconomy. This strategy combines the comparative advantage of crop production and identification of regional trade and business opportunities to effectively use its industrial and food processing infrastructure. Importantly, Thailand has taken a multisectoral and multistakeholder approach to developing its bioeconomy strategy and policies, with public sector STI systems working with the private sector to identify research priorities for the bioeconomy.

In **Brazil**, the government has identified several strategic streams for its bioeconomy, driven by a governance structure that coordinates research and agribusiness, structures global cooperation and a business council, and provides a supportive policy system. The bioeconomy facilitates the identification of opportunities for value addition through biotechnological processes and the effective and sustainable use of biomass. At the same time, Brazil has developed strategic partnerships and alliances with countries that have shown initial ambition for developing their bioeconomy, including in the LAC region and Europe.

Recommendations From the Country Analyses

The case studies have demonstrated the following important actions for bioeconomy strategies in the African context:

- Elevating bioeconomy to a top policy priority and working across sectors and in continuous dialogue with all stakeholders
- Prioritizing agricultural innovation and sustainability
- Developing and implementing bioenergy policies
- Strengthening ecosystems for entrepreneurship and innovation in bio-based sectors
- Recognizing the importance of continuously updating and filling knowledge and data gaps as a key to increasing the competitiveness of countries' bioeconomies

- Participating and partnering in international platforms, sharing knowledge with other countries and regions, and improving coherence in sustainability objectives of the bioeconomy with climate and biodiversity and other multilateral agreements

Furthermore, to successfully transition to a bioeconomy, countries must develop a coherent national bioeconomy strategy and investment plan that is cross-sectoral and involves multistakeholder engagement, ensuring inclusive growth, sustainable development, and policy coherence at the national and subnational levels.

Insights from the case studies can inform a set of sound and more specific policy and institutional recommendations that leverage the strengths and address the challenges each country faces in the development of their bioeconomy and sustainable practices:

Specific Policy Recommendations:

1. **Develop and implement coherent national strategies for sustainable bioeconomy**
   Following Namibia's example, bioeconomy strategies must include all sectors, and their respective development plans must be anchored in sectoral policies and frameworks to ensure comprehensive and inclusive growth. These strategies should maintain policy coherence to drive the bioeconomy forward and prioritize sustainable resource use, economic diversification, and environmental protection.

2. **Promote research and innovation in bio-based technologies**
   Countries should focus on strengthening R&D in sectors identified as gateways to the bioeconomy, including bio-based technologies and solutions as seen in Ghana's focus on neem-derived biopesticides as an eco-friendly and cost-effective plant protection measure or Namibia's focus on biomass to foster innovation and sustainable utilization of resources. Thailand has shown leadership in applying a bioeconomy approach to its healthcare and pharmaceutical and its ecotourism sectors. Brazil shows a focus on value addition to primary products, recycling of biowastes, and development of innovative bioproducts, such as biofertilizers, bio inputs, and bioethanol production.

3. **Support the use of biomass, especially in strategic sectors such as the energy sector and for other uses**
   Uganda's utilization of biomass and waste for a significant portion of its energy supply highlights the importance of diversifying energy sources. Encouraging the multipurpose use of biomass for energy, food, and feed production as part of a circular bioeconomy can provide a model for energy security and sustainability. In addition, Ghana's example of following the lead of the National Renewable Energy Action Plans and leveraging agencies such as the ECOWAS Centre for Renewable Energy and Energy Efficiency can encourage other countries to develop and implement policies that promote the use of renewable energy within their bioeconomy strategies. In Brazil, the 2018 bioeconomy-specific action plan provides an overarching framework for integrating bioeconomy subsectors such as agriculture, forestry, biodiversity, environmental protection, and others. The sustainable production, processing, and value addition to biomass through the development of innovative products and chemicals are the action plan's key strategic objectives and critical to achieving its integrated approach.

4. **Enhance capacity building and knowledge sharing**
   Invest in capacity-building initiatives for institutions and stakeholders involved in the bioeconomy to ensure they have the necessary skills and knowledge to devise bioeconomy strategies, policies, and targeted interventions. This includes capacity-building initiatives for farmers and businesses in the use and application of sustainable practices and technologies, as well as improving evidence-based decision-making processes and policy development, such as Ghana's example of utilizing the insights from *Agriculture in Ghana (Facts & Figures)* (Ghana, Ministry of Health 2021) to improve decision-making processes and policy development in the agricultural sector. In addition, peer-to-peer dialogue and sharing of knowledge and best practices between countries can facilitate learning and adaptation across different contexts. A good example is Uganda's comprehensive approach to developing its bioeconomy. Finally, policies, investments, and incentives must also be put in place to ensure that the skills and knowledge required for the development and growth of the bioeconomy are also included in school and university curricula.

5. **Promote sustainable agricultural and forestry practices**
Develop policies and support initiatives aimed at rehabilitating degraded lands and promoting sustainable resource management practices, particularly for bush control and biomass utilization, as well as food security as a primary sustainability objective, taking cues from Namibia's strategies for bush resource management. Initiatives such as controlled bush thinning and the transformation of encroacher bush to value-added products can offer environmental and economic benefits supporting bioeconomy sectors such as agriculture, energy, and forestry. These economic benefits include much-needed employment and income opportunities, especially for women and young people. Another example is Ghana's promotion of eco-friendly agricultural practices such as the use of biofertilizers.

6. **Facilitate access to finance for bioeconomy projects**
Provide financial incentives and support mechanisms for enterprises and projects that contribute to the bioeconomy. Bioeconomy strategies should therefore not only be designed, but they must also be financially costed and result in an investment plan to mobilize necessary resources from national budgets and large volumes of investment from financial institutions and investors and through global financing mechanisms (such as climate finance mechanisms). Fostering an investment-friendly environment will encourage innovation and the uptake of sustainable practices across sectors, such as increasing investments in clean energy technologies in Uganda.

Institutional Recommendations:

7. **Foster cross-sectoral partnerships and collaboration to promote development of the bioeconomy**
Encourage collaboration between governmental, private sector, and research institutions similar to the successful collaborations in Ghana and Thailand, or Uganda's approach involving institutions like NARO and Makerere University's CAES. This ensures that innovation and sustainability are at the core of developing the bioeconomy. It is also important to strengthen the operational capacity of key ministries to enable effective interministerial coordination, as well as at the subnational and regional levels, as done in Namibia, and deepen the understanding of how a transition to a bioeconomy benefits all sectors.

8. **Engage in regional and international cooperation**
Stronger and more effective regional and international partnerships for technology transfer, trade, and investment in bioeconomy sectors can enhance the scalability and impact of bioeconomy initiatives beyond national borders. It can also support creating and accessing better data specific to the bioeconomy and help coherence and coordination at the international level, particularly toward global common objectives of climate and biodiversity action. The EAC has taken the lead in Africa to develop a regional bioeconomy strategy, providing for more regional integration on bioeconomy. As other RECs embark on the design of their respective regional strategies, Africa could move toward a continental bioeconomy strategy that aligns with other continental ambitions on green growth and economic development.

Finally, across all the country studies, the gateway sectors that mainly drive the transition to a bioeconomy are agriculture, renewable energy, and biomanufacturing industries. These are the key sectors leading the transition to a bioeconomy, leveraging countries' extensive biomass-based resources and other biological resources, while at the same time promoting economic growth, social equity, and sustainable resource management.

Making the Business Case for a Bioeconomy in Africa

Julius Ecuru and Philip Osano

Introduction

The bioeconomy involves the use of scientific knowledge to add social and economic value to biological resources in an environmentally sustainable way. It is widely regarded as a growth and development pathway that contributes to lower carbon emissions, better preservation of biodiversity, and greater prospects for decent jobs and livelihoods (Malabo Montpellier Panel 2022; IACGB 2024). A bioeconomy is attractive to policymakers because of attributes that are benign to the environment and appealing to consumers: (1) it is biologically based, using biomass (biodiversity) as the primary raw material; (2) it is scientifically driven, underpinned by innovation, for example, in the production of new goods and services; (3) it is cross-sectoral, involving the expertise and participation of diverse disciplines—agriculture, environment, health, industry, and education; and (4) it is sustainable, reducing emissions and minimizing waste. In other words, a life cycle analysis of any biologically based product or process should find a net environmental benefit for both inputs and outputs. Social benefits might include equity, justice, and inclusiveness in using biological resources, as well as management of the necessary trade-offs when investments are made involving the use of biodiversity, water, and land resources. Ultimately, the added value of the bioeconomy is expressed in healthier foods; safer medicines; cleaner energy; useful substances from biological waste and other environmentally friendly processes in the manufacturing, distribution, and consumption of goods and services; and most of all, decent jobs for the largely youthful population in Africa.

Why a Bioeconomy?

Regions such as Africa, which have significantly lower carbon emissions than the rest of the world, could have a competitive advantage in developing sustainable bioeconomies. Africa has abundant renewable biological resources, including crops, forests, fish, animals, and microorganisms, to which value can be added in a sustainable way, producing novel food; safer medicine; environmentally friendly materials, products, and textiles; and bioenergy. The continent also has a large land mass, of which about 60 percent is arable. Therefore, it can support both large and smaller but intensive agricultural production. With advanced bioprocessing and biomanufacturing, biologically based value-added products and services can be produced and delivered to consumers in a sustainable manner. The continent can also contribute to carbon emissions reduction by adopting innovative pathways that use microorganisms to capture carbon directly from the air (Lang 2022).

Making a Bioeconomy Business Case

A business case for a bioeconomy in Africa can be made along the dimensions of economic stability, biodiversity richness, emerging biotechnology capacity, agricultural potential, and forward-looking bioeconomy policies. Each of these dimensions is explained below.

Economic Stability

Most countries in Africa now have the fundamentals for economic growth. There is relative macroeconomic stability in several countries where markets are liberal and fiscal policies are functional. The African Development Bank Report 2024 projects growth of at least 4.0 percent per year in the medium term (AfDB 2024). Much of this growth is driven by investments in the security of persons and property as well as in infrastructure, including roads, railways, and electricity. Foreign companies have also expressed increasing interest in investing in Africa. However, growth must increase to at least 7 percent per year and be consistently maintained there if Africa (where gross national incomes per capita range between US$3,996 [1] and $12,375) is to realize its ambition of achieving upper-middle-income status in the medium and long term. Scholars and policymakers believe that diversifying sources of growth would enable the continent to achieve higher growth rates. A bioeconomy arguably offers additional

1 All dollar amounts are in US dollars.

opportunities for economic diversification and economic growth, and enables countries to fully benefit from the African Continental Free Trade Agreement (ACFTA), which was signed on March 21, 2018, in Kigali, Rwanda (World Bank 2020). ACFTA not only provides opportunities for regional trade but also helps Africa to connect with global bioeconomy supply chains. Countries would, however, need to step up efforts in adding value to biological resources, including biowaste conversion. A relatively easy way to start could be through adding value to multiple-use, starchy crops like maize, sorghum, and cassava, which are widely grown in Africa south of the Sahara and can serve both food and feed needs. Another is through developing industrial applications, for example, in the production and use of sustainable biofuel and other industrial chemicals (Duarte Pasa, Almeida Scaldadaferri, and dos Santos Oliveira 2022). This type of targeted value addition can create opportunities for linking primary production to bioprocessing offtakers and eventually to global supply chains for sustainable green chemicals.

The World Business Council for Sustainable Development Report 2020 projects that the global bioeconomy is growing at 3.3 percent annually and will be a $7.7 trillion market by 2030 (WBCSD 2020). By adding value, numerous uses of biological resources can be found: for example, biowaste can be turned into biofertilizers and energy, and high-value green chemicals can be recovered from the waste. These new uses bring new business prospects and jobs, thus diversifying the economy. The extent of the economic impact of a bioeconomy requires more study. Nevertheless, anecdotal evidence of emerging biologically based innovations—such as biological waste conversion using black soldier flies (BSF) and earthworms—show a growing number of small- and medium-size enterprises adopting nature-positive solutions in the crop and livestock production systems of East, West, and Southern Africa, increasing incomes and job opportunities. Farmers are using BSF larvae as an affordable and environmentally sustainable alternative protein in fish and poultry feed. They also use frass (compost from BSF) fertilizer in vegetable and fruit farming, generating net environmental and economic benefits (Beesigamukama, Subramanian, and Tanga 2022; Beesigamukama et al. 2022; Abro et al. 2020; Chia et al. 2020).

Biodiversity Richness

Africa is endowed with rich biodiversity, including plants, animals, insects, and microorganisms that offer a strong foundation for developing a bioeconomy. This biodiversity also encompasses important indigenous or traditional knowledge, which provides leads for scientific discovery and validation. During the COVID-19 pandemic, several African communities resorted to herbal remedies from the wild to manage symptoms of the disease. In Uganda, for example, an herbal medicine (Covidex) developed by a private company (Jena Herbals Limited) and a university (Mbarara University of Science and Technology) was demonstrated to be effective in relieving severe symptoms of COVID-19 (Ogwang et al. 2024). Other groups in several parts of the continent used immune boosters from all kinds of herbs, including mint, ginger, and lemon, to make concoctions and drinks that many believed were useful in managing the disease (Xinhua 2021).

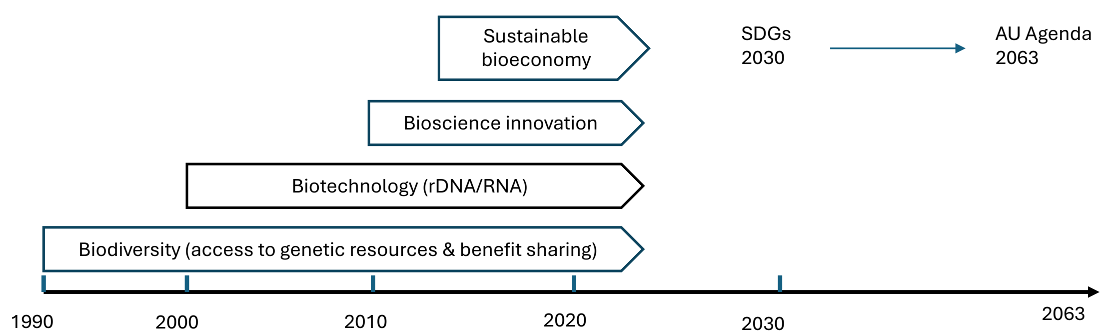
In the early 1990s, conversations addressing access to genetic resources and benefit sharing under the Convention on Biological Diversity (CBD) triggered interest in the untapped value of biodiversity (CBD 1992). The CBD recognizes that genetic resources and the traditional knowledge associated with them have economic and social value. The principle of justice enshrined in the CBD is that communities that are custodians of genetic resources should also benefit from their use. The CBD argues for a fair and equitable distribution of benefits and burdens with respect to the conservation and use of biodiversity. This argument posits that traditional or indigenous knowledge associated with biodiversity provides important leads for screening active compounds that are used in the food and pharmaceutical industry. The argument also extends to the use of beneficial microbes collected from communities where these microbes are endemic to make economically useful products such as microbial enzymes for use in manufacturing. Consequently, several countries now have mechanisms to grant access and negotiate benefits, including prior informed consent and material transfer agreements. These mechanisms have been codified in the 2010 Nagoya Protocol on Access and Benefit-Sharing of genetic resources and institutionalized in most African countries that are party to the CBD (CBD 2010). However, benefit-sharing arrangements should be developed in such a manner that they do not hinder progress in the beneficial use of biological resources and the advancement of the bioeconomy.

Biotechnology Capacity

Related to the CBD discussion is the advent of modern biotechnology, that is, the use of recombinant DNA (rDNA) in pharmaceutical, crop, and livestock production. The use of rDNA techniques, especially in crop improvement, continues to attract both significant interest and controversy in Africa. Experimental trials of genetically modified (GM) crops with resistance to particular diseases, such as maize resistant to the maize stem borer, cotton resistant to the ball worm, bananas resistant to nematodes and banana wilt disease, cassava resistant to the cassava brown streak virus, and soy with herbicide tolerance, to name but a few, have been successfully conducted in most African countries, including Burkina Faso, Ghana, Kenya, Nigeria, South Africa, and Uganda. All of these trials demonstrated success and high efficacy in pest and disease control as well as tolerance to drought conditions. Studies have shown that farmers in South Africa who adopted white GM maize that is resistant to the devasting maize stem borer could increase their yields by up to 35 percent compared with conventional (non-GM) varieties (Koch 2004), an outcome associated with welfare benefits of nearly $700 million (Ala-Kokko et al. 2021). However, so far only GM cotton has been widely released commercially—first in Burkina Faso, Ethiopia, and Sudan, with other countries considering the same to boost their textile industry. Increasingly, modern biotechnology applications are finding niches in industrial manufacturing, signaling that besides meeting food security challenges, forming links with industry is also critical (Weisenfeld et al. 2023). Industry provides much-needed jobs and increases incomes for families when their produce is linked to agro-processing and to markets.

Perhaps the greatest gains so far have been investments in modern biotechnology, especially in academic and research settings, that have led to the rapid advancement of bioscience tools and knowledge. These investments include micropropagation techniques and selection markers for crops of interest for breeding that have had immediate applications in crop and animal improvements. Amid the increasing maturity of bioscience knowledge platforms and the production of several biologically based prototypes in public research institutes—and alongside the need to conserve biodiversity and reduce emissions—policymakers and scholars now think that a bioeconomy would be an improved growth pathway, with increased inclusion and relevance to the economy. Furthermore, this pathway should be closely linked to the Sustainable Development Goals for 2030 and the African Union Agenda 2063 (AUC 2013) (see Figure FI.1). These development frameworks call for sustainable industrialization, climate change mitigation, skills for youth, and societal transformation in a positive way (African Union Commission 2013).

FIGURE FI.1—THE EVOLVING AFRICAN BIOECONOMY



Source: Authors' illustration.
Note: SDGs = Sustainable Development Goals; AU = African Union.

TABLE FI.1 —KEY PRODUCTIVE SECTORS OF THE EAST AFRICAN ECONOMY

Country	Population in millions	GDP (US$bn)PPP	Industry	Agriculture	Services	Manufacturing	CO2 Emissions (kt)
Burundi	12.6	2.78	10.6	28.7	44.8	9	713
Ethiopia	120.3	111.27	21.6	37.6	36.3	5	18,098
Kenya	53.0	110.35	17.0	22.4	54.4	7	19,447
Rwanda	13.5	11.07	20.3	24.1	47.8	9	1,382
Tanzania	63.59	67.87	29.8	25.9	34.3	8	14,436
Uganda	45.85	40.53	27.1	23.8	41.8	16	5,675

Source: World Bank (2023).
Note: GDP = gross domestic product; bn = billion; PPP = purchasing power parity; kt = kilotons.

Agricultural Potential

Agriculture provides the main feedstock for the bioeconomy. Africa has 60 percent of the world's arable land (AGRA 2022), which if sustainably used can provide the much-needed biomass for the bioeconomy. In East Africa, for example, agriculture contributed on average 30 percent of the gross domestic product (GDP) in 2023 (see Table FI.1) (World Bank 2023). Countries are eager to reduce the share of agricultural GDP while increasing the share of manufacturing through value addition and agro-processing. In a modern industrialized economy, manufacturing should contribute more than 20 percent of GDP (World Bank 2023). This represents an opportunity to advance the bioeconomy in Africa given that growth in manufacturing is likely to be biobased, taking advantage of the agricultural produce and feedstock.

Forward-looking Bioeconomy Policy

The bioeconomy began gaining momentum in the United States and in Europe through a knowledge-based bioeconomy initiative in the early 2000s in the European Union (EU) (Patermann and Aguilar 2018). This initiative later evolved into a bioeconomy roadmap in the United States in 2012 and a bioeconomy strategy for the EU in 2012. South Africa was proactive and in 2013 became the first African country to develop a dedicated bioeconomy strategy, closely following developments in the EU; and in June 2024 Namibia published its national bioeconomy strategy, becoming the second country in Africa with such a strategy. To date, more than 65 countries all over the world have developed dedicated bioeconomy strategies (IACGB 2024). In Africa, the East African Community (EAC) is the first regional economic bloc to develop a dedicated regional bioeconomy strategy (EAC 2022). The strategy is anchored on the sustainability pillars of environmental sustainability, climate change adaptation and mitigation, and sustainable production and consumption. Priorities for the strategy include food security and sustainable agriculture, health and well-being, sustainable energy, and biologically based industrialization. Implementation of the strategy harnesses opportunities for global collaboration and partnerships to advance the bioeconomy according to the unique needs and values of the region. In particular, value addition, biowaste conversion, and ecosystem services are key enabling activities promoted by the strategy. The strategy is appealing because it combines the different productive and economic sectors to focus on value addition or creation as well as the development of prospects for sustainable businesses and jobs. The cross-sectoral nature of the EAC regional bioeconomy strategy is in tandem with the global consensus that views a bioeconomy as "sustainable," emphasizing low carbon emissions, biodiversity conservation, and no pollution of air, water, or land (von Braun 2018).

Conclusion

There is a growing recognition that the development of a bioeconomy in Africa will increase the economic and social value of regionally traded, biologically based goods and services. These goods and services emanate from technologies and investments aimed at adding value to agricultural production; converting biological waste into useful material (thus promoting circular production); and connecting national, regional, and global biologically based value chains. Consequently, countries with a vibrant bioeconomy would arguably be the ones to fully participate in and benefit from the ACFTA. Given its distributive nature, a bioeconomy will incentivize micro-, small-, and medium-size enterprises and the informal sector, which together make up a large part of the African economy. Therefore, African countries should develop bioeconomic clusters of innovation and entrepreneurial activities based on renewable biological resources and their unique needs and natural advantages. These efforts should culminate in what would become the African bioeconomy, connecting with the rest of the world.

CHAPTER 10

Innovative Financing Mechanisms for Climate Adaptation in African Agrifood Systems

Cecilia D'Alessandro, Daniel Adeniyi, and Lade Araba

Introduction

Agrifood systems are a leading cause of climate change globally, as they are responsible for a third of anthropogenic greenhouse gas (GHG) emissions, the majority of which are tied to agricultural production (39 percent), followed by land use (32 percent) and supply chain activities (29 percent). Moreover, unsustainable agricultural practices continue to drive 80 percent of the loss of terrestrial biodiversity, soil degradation, and deforestation and are responsible for 70 percent of global freshwater withdrawals. GHG emissions are projected to increase by 60 to 90 percent through 2050 unless corrective action is taken (Apampa et al. 2021). Africa's share of global GHG emissions is small (2 to 3 percent) but rising, with agriculture and land use change as major contributors (Adolph, Griffiths, and Hou-Jones 2023; FAO 2022).

At the same time, climate change poses unprecedented challenges to agrifood systems worldwide. Despite Africa's marginal contribution to GHG emissions, the continent is highly vulnerable and disproportionately affected by climate change impacts because of its low adaptive capacities and strong dependence on climate-sensitive sectors. Moreover, the continent is warming faster than the world average on land and sea, with temperatures rising across all regions. Erratic rainfall patterns and extreme weather events also increasingly threaten African agrifood systems, resulting in crop failures, increased food prices, reduced job opportunities, and heightened food and nutrition insecurity (IPCC 2022). Small-scale farmers, operating predominantly on land plots ranging from 0.3 to 3 hectares, face heightened vulnerability to seasonal climate fluctuations, including droughts and floods. Rural women and girls, in particular, rely heavily on food systems for their livelihoods and often possess limited resources to prepare for and adapt to climate change (Adeniyi 2023a).

Adaptation measures in agriculture and food systems are therefore urgently needed to mitigate the adverse effects of climate change, reduce the continent's vulnerability to climate hazards, and foster the development of sustainable, resilient, and inclusive agrifood systems. Acting promptly is crucial, as postponing action will incur greater costs for the continent in the future (Meattle et al. 2022). Box 10.1 provides some examples of existing adaptation options in African agrifood systems.

BOX 10.1—ADAPTATION OPTIONS IN AFRICAN AGRIFOOD SYSTEMS

A wide variety of adaptive solutions can help reduce African agrifood systems' vulnerability to climate change risks. They include on-farm practices such as crop diversification (for example, switching to less water-intensive crop varieties and species or integrating legumes as nitrogen-fixing crops that can improve soil fertility); regenerative agricultural practices, conservation agriculture, and agroecological approaches; land restoration and agroforestry; altered timing of key farm activities such as planting and harvesting; and integrated pest management. Another key adaptive measure is investment in research and innovation and extension services (for example, for the development and uptake of climate-resilient seed varieties). In addition, the use of digital tools for climate information services, such as early-warning systems and seasonal weather forecasts, can support farmers' adaptation efforts. Other examples of adaptive actions are disaster and emergency planning, social safety net interventions related to agricultural livelihoods, and the use of insurance products that help farmers manage weather risks (FAO 2023; GCA 2023; Knaepen 2022).

Developing innovative, sustainable bioeconomy* solutions can also contribute to climate change adaptation, while often offering mitigation and carbon sequestration co-benefits. Examples include the promotion of ecosystem restoration and the sustainable management of forests and fisheries; the improvement of soil health and water retention capacity; the development of new value-added products from agricultural waste; investments in the production of modern bioenergy; and the support of indigenous livelihoods based on biological products and services (Gomez San Juan, Harnett, and Albinelli 2022; Malabo Montpellier Panel 2022b).

Identifying and assessing adaptation options is highly context specific, with the most effective adaptation options varying by specific locality, farming system, and farmer socioeconomic situation. Co-benefits and trade-offs also vary depending on the socioecological context (IPCC 2022).

*Bioeconomy is defined as an economy based on the sustainable and circular use of biological resources and processes to produce food, feed, and bio-based products and services for all economic sectors (Malabo Montpellier Panel 2022b).

However, current global financial flows for adaptation are insufficient to meet the escalating needs of vulnerable communities. Developed countries are still falling short of their pledge to channel US$100 billion [1] of climate finance per year to developing nations by 2025 under the United Nations Framework Convention on Climate Change (UNFCCC), including doubling adaptation flows to $40 billion per year (as promised at the 26th United Nations Climate Change Conference [COP26] in Glasgow), and increasing the share of adaptation finance as part of the New Collective Quantified Goal on Climate Finance (Knaepen and Dekeyser 2022). Overall, Africa has access to a relatively small share of international climate finance, estimated at only 5 percent of the global finance available (Malabo Montpellier Panel 2022a).

Moreover, while agriculture and food systems have gained greater prominence in UNFCCC processes in recent years—with the agreement on the Sharm el-Sheikh joint work on climate action in agriculture and food security at the 27th United Nations Climate Change Conference (COP27) and the COP28 Leaders Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action at the 28th United Nations Climate Change Conference marking significant milestones—sustainable food systems transformation remains chronically underfunded, making up only about 4 percent of climate finance between 2019 and 2020 (Chiriac, Vishnumolakala, and Rosane 2023a). Only 1.7 percent of global climate finance targets smallholder farmers, reflecting low levels of inclusivity of climate finance mechanisms (Chiriac and Naran 2020).

While the need to unlock additional climate adaptation financing and fulfill global commitments remains pressing, many African governments have started earmarking domestic public funds for adaptation activities to support their agrifood systems and are devising national frameworks to mobilize and deploy funding through various policy and institutional innovations (Malabo Montpellier Panel 2022a). Several nations, including several in Africa, formulated their nationally determined contributions (NDCs), national adaptation plans (NAPs), and national food systems pathways in the run-up to the 2021 United Nations Food Systems Summit; however, implementation efforts remain fragmented and inadequate, with limited coordination among countries' food system pathways, climate policies, and investment strategies.

Unlocking climate finance for food systems adaptation faces several challenges. Some are typical of climate finance, while others are inherent to the nature of the agrifood sector— such as significant perceived risks, small ticket sizes, and high transaction costs. To overcome these hurdles, strengthening capacities at all levels is essential. Moreover, traditional funding sources, such as grants and loans, will be insufficient to mobilize the required funds for food systems adaptation. This necessitates exploring alternatives, including attracting private sector investment. Blended finance mechanisms, which combine public and private funds, and the design of scalable projects attractive to investors—including sustainable bioeconomy projects—may be promising avenues (Adeniyi 2023a).

Recognizing the critical role of finance and investments in building adaptation and resilience and promoting the transformation to sustainable food systems, this chapter explores innovative financing mechanisms that can fill the funding gap for climate action in African agrifood systems, with a focus on adaptation.

The chapter is structured as follows. First, we present an overview of the current state of climate finance flows to food systems in Africa. Second, we analyze the prevailing barriers that hinder the effective mobilization and use of climate finance for food systems adaptation in Africa. Third, we highlight the opportunities arising from a wide range of innovative financing tools and mechanisms to mobilize additional finance from both the public and the private sectors, with a focus on blended finance. Fourth, we describe the key building blocks to a conducive enabling environment for climate-related investments in agrifood systems. Last, we provide concluding remarks.

Overview of Current Financing Trends

This section provides a brief overview of the current state of climate finance [2] flows to food systems in Africa, with a focus on adaptation finance. It evaluates various sources of finance to assess their adequacy in fulfilling Africa's food systems adaptation objectives. Our analysis shows that current climate finance

1 All references to dollars are to US dollars.

2 There is no agreed-upon definition of climate finance. However, the UNFCCC provides an operational definition: "Climate finance refers to local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions to address climate change" (Galbiati et al. 2023).

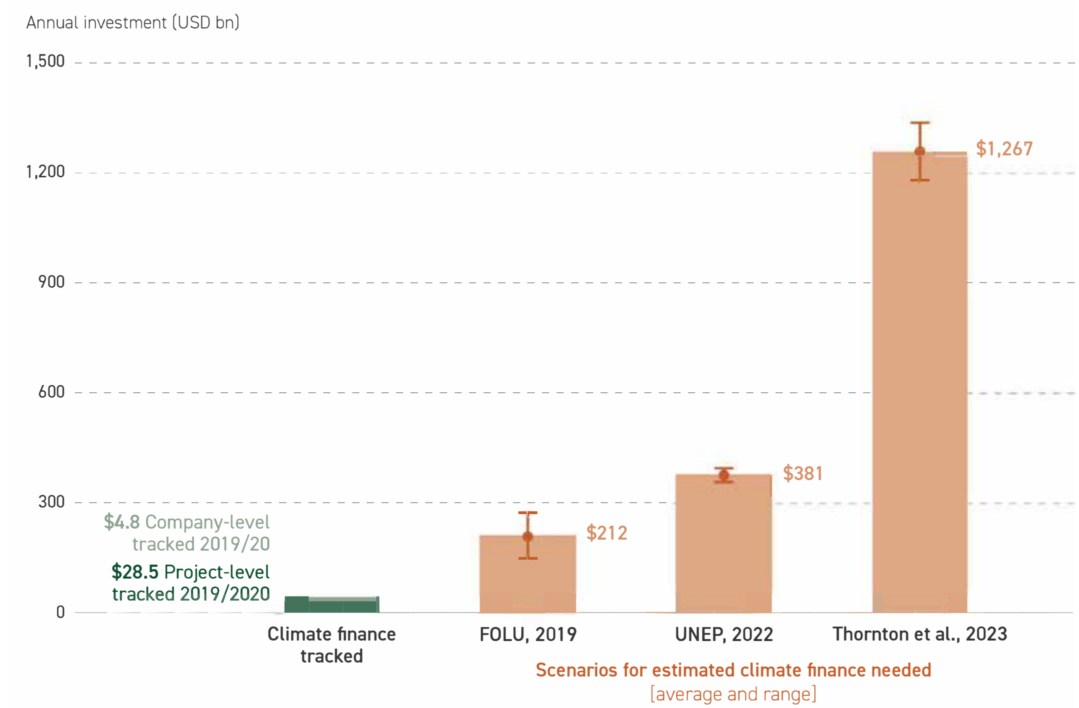
flows to agrifood systems fall significantly short of meeting Africa's requirements. As such, both public and private actors need to significantly step up funding to address Africa's climate finance needs in agrifood systems.

Methodological Note

The assessment of climate finance flows for adaptation in agrifood systems, particularly in developing countries, is challenging because of insufficient transparency and reporting (Chiriac, Vishnumolakala, and Rosane 2023a). Inconsistencies in the official reporting of climate finance within the UNFCCC and difficulties distinguishing funds allocated for dual-purpose activities (both mitigation and adaptation) complicate the accurate assessment of progress in the goal of doubling adaptation finance (Knaepen and Dekeyser 2022).

In addition, there is still a paucity of information on the adaptation finance gap. Accurately assessing the financial requirements for adaptation requires reliable data, proficient modeling, and sufficient technical expertise. Without those components, assessments of needs tend to significantly underestimate the actual cost of adaptation efforts. Key challenges to determining adaptation needs include uncertainties about future risks, discrepancies in objectives, and differences in the geographic and sectoral scope of analysis. For example, recent analyses suggest that African countries' predicted adaptation finance needs, based on NDC submissions, are likely less than half of those actually required. Notably, only 28 African countries provided cost estimates for adaptation in their NDCs (GCA and CPI 2023). A lack of rigor in the identification of vulnerabilities, priority sectors and actions, and costs contributes to such underestimation—with most NDCs lacking a quantitative assessment of adaptation goals and concrete figures in terms of financial needs (AfDB 2019).

FIGURE 10.1—TRACKED CLIMATE FINANCE FLOWS TO AGRIFOOD SYSTEMS COMPARED WITH NEEDS



Source: Chiriac, Vishnumolakala, Rosane (2023a).
Note: USD bn = billion US dollars.

In this section, we rely on recent estimates of climate finance flows provided by the Climate Policy Initiative (CPI), as well as data collected by the Organisation for Economic Co-operation and Development (OECD) Development Assistance Committee (DAC) as compiled in a report by Galbiati and colleagues (2023). [3] As for estimates of adaptation finance needs, we rely on recent reports from the Global Center on Adaptation, CPI, and the Malabo Montpellier Panel (Malabo Montpellier Panel 2022a), as well as scenarios developed by the Food and Land Use Coalition (FOLU 2019), the United Nations Environment Programme (UNEP 2022), and Thornton and colleagues (2023).

3 The OECD DAC data are a comprehensive and accurate source of information about climate-related developmental flows from both bilateral and multilateral providers. This source includes official development assistance, other official flows, private grants, and private amounts mobilized and reported by DAC and non-DAC members, including multilateral institutions and private philanthropy. CPI, on the other hand, considers the entire architecture of climate finance and a broader range of financial aspects related to climate change, including public and private sector investments and domestic and nondevelopmental private climate finance.

Recent Trends in Climate Finance Flows

According to CPI's 2023 Global Landscape of Climate Finance, the amount of climate finance flowing to agrifood systems globally is extremely low. Agrifood systems received only 4.3 percent of total climate finance tracked at the project level in 2019–2020, with an annual average of $28.5 billion. Of that tracked amount, 26 percent went to adaptation ($7.3 billion), 51 percent ($14.4 billion) targeted mitigation objectives, and 23 percent ($6.7 billion) was dual-objective. In terms of sectoral allocation, two-thirds of adaptation finance targeted agriculture, while only 2 percent and 1 percent, respectively, targeted forestry and fisheries projects. Food loss and waste and low-carbon diets saw negligible investments, representing a missed opportunity in terms of adaptation for agrifood systems.

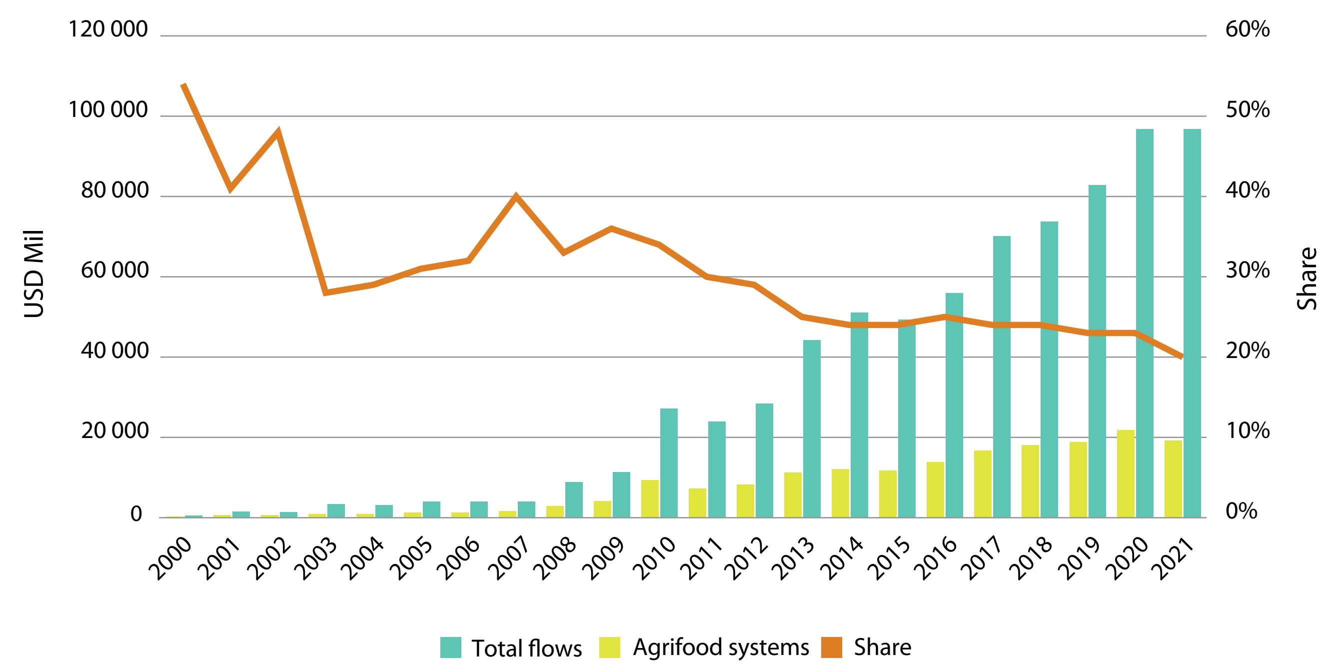
Comparing these numbers with the estimated climate-related investment needs for agrifood systems globally reveals that investments in agrifood systems need to increase, at a minimum, seven times from 2019–2020 levels to meet climate adaptation and mitigation objectives by 2030 (Figure 10.1) (Chiriac, Vishnumolakala, and Rosane 2023a).

Moreover, a recent report from the Food and Agriculture Organization of the United Nations (FAO) highlights that the share of climate-related development finance flowing to agrifood systems globally is trending downward. After a peak year in 2020 (with an allocation of $21.8 billion), climate finance for agrifood systems dropped by 19 percent in 2021—possibly also as a result of a shift in priorities due to the COVID-19 pandemic (Figure 10.2) (Galbiati et al. 2023).

Africa south of the Sahara received 16 percent of the agrifood climate finance flows tracked by CPI in 2019–2020,a total of $4.4 billion. It is the second-largest destination after East Asia. Nonetheless, considering how vulnerable food and agricultural production is in Africa, the financial gap to meet adaptation needs is staggering. The adaptation financing needs for Africa's agriculture, forestry, and land use sector and its water sector will amount to approximately $78 billion per year until 2030 (Malabo Montpellier Panel 2022a). Box 10.2 discusses the economic benefits of investing in adapting Africans agrifood systems versus the crippling costs of inaction.

Most of the tracked flows went to adaptation projects in agriculture, including, among others, the promotion of drought-tolerant crops, the provision of extension services for climate-smart agriculture and water management, and the establishment of early-warning systems providing climate and weather information (Chiriac, Vishnumolakala, and Rosane 2023a). Several projects aimed to

FIGURE 10.2—SHARE OF CLIMATE-RELATED DEVELOPMENT FINANCE TO AGRIFOOD SYSTEMS AGAINST GLOBAL FLOWS



Source: Galbiati and colleagues (2023).
Note: USD mil = million US dollars.

BOX 10.2—THE ECONOMIC BENEFITS OF ADAPTATION ACTION

Investing in adaptation action in African agrifood systems makes economic sense. According to the Global Center on Adaptation, the annual cost of inaction, including repeated disaster relief and recovery from floods and droughts, could reach as high as $210 billion, equivalent to approximately 12 percent of the continent's gross domestic product (GDP). Regional impacts may exacerbate this, with Southern Africa potentially losing 10 percent of its GDP by 2050, and West and East Africa up to 15 percent by the same year. Investing in research, water management, infrastructure, land restoration, and climate information services could cost $15 billion per year, representing just 0.93 percent of GDP. This indicates that the cost of taking action on climate adaptation and food systems is significantly less than the cost of inaction. Moreover, well-designed adaptation investments can alleviate the burden of climate impacts and yield economic, social, and environmental benefits. Adaptation not only reduces losses but also generates positive economic returns and fosters sustainable development outcomes. For example, tailored adaptation programs in agriculture can produce co-benefits across various sectors, contributing to mitigation efforts and sustainable development objectives (Malabo Montpellier Panel 2022a).

secure land tenure rights for farmers—an important enabler of investments in long-term, sustainable land management practices, as well as a key form of collateral that can improve farmers' ability to access financing (Chirian and Naran 2020). Africa south of the Sahara was the largest recipient of forestry adaptation finance (40 percent). Nonetheless, given the acute vulnerability in the region—where less than a quarter of forests are under forest management plans—the scale of these financial flows is far below the region's needs (FAO 2020 cited in Chiriac, Vishnumolakala, and Rosane 2023a).

The adaptation finance gap in African agrifood systems is particularly large when looking specifically at small-scale agrifood systems. Globally, less than 1 percent of climate finance targets this sector, amounting to just $5.5 billion, which falls far short of the needs of farmers and other value chain actors (Chiriac, Vishnumolakala, and Rosane 2023b).[4] Of this amount, $1.86 billion (that is, 34 percent, the largest share) targeted Africa south of the Sahara, reflecting the predominance of small-scale farms in the region. However, considering that Africa's agriculture and food systems face the most significant climate vulnerability on a global scale, the need for further funding is urgent.

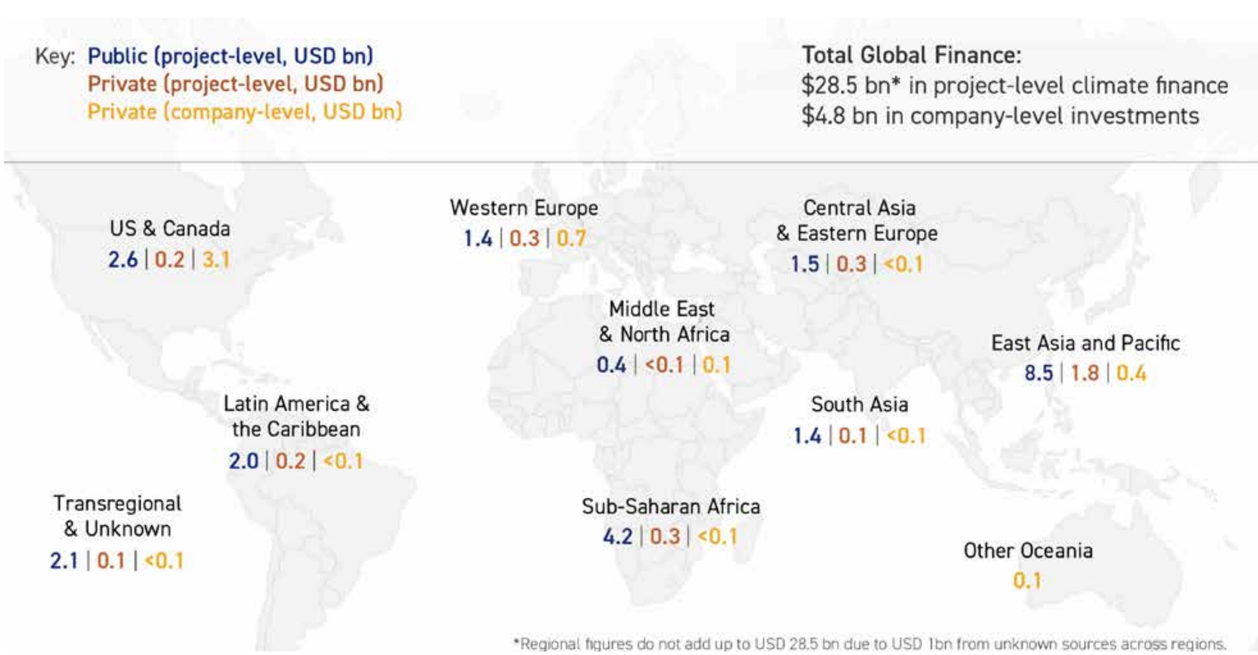
Moreover, current climate finance flows inadequately address gender inequality and social exclusion. The impacts of climate change are likely to aggravate existing gender inequalities and marginalization patterns as a result of distinct gendered vulnerabilities and capacities to face and recover from climate impacts, as the Intergovernmental Panel on Climate Change's *Fifth Assessment Report* underscores (Schalatek 2022). Rural women, in particular, rely heavily on agrifood systems for their livelihoods, but financial institutions see them as riskier borrowers given their limited land ownership, lack of collateral, and weaker credit history. This limits their ability to access financial support and adapt to the changing climate, making them even more vulnerable to its impacts (FAO 2024). Policies and programs that consider the specific needs and contributions of both women and men have been associated with increased effectiveness in achieving their adaptation objectives (UNEP 2023). Nonetheless, gender-specific considerations are still largely overlooked in global climate finance flows, including those targeting agrifood systems. A lack of awareness and understanding among climate finance resource partners, as well as inadequate data and research on the gender dimensions of climate change and climate finance, are among the main reasons for this oversight (Galbiati et al. 2023; Meattle et al. 2022; Pettinotti, Cao, and Kamninga 2023).

Concerning the finance sources, nearly all financial flows tracked by CPI in 2019–2020 were international, coming from Western Europe (47 percent) and North America (18 percent).[5] African agrifood systems rely primarily on public climate finance, mostly from multilateral development finance institutions (DFIs) through concessional debt and grants, while private funding is negligible (Figure 10.3). Also, Africa south of the Sahara receives more than half of all philanthropic funding serving agrifood systems— much of which is disbursed in grants (targeting the promotion of agricultural adaptation options such as regenerative agricultural practices, integrated pest management, and climate-resilient crops). These trends reflect the existing barriers to financing

4 Although an estimate of the climate finance needs of small-scale agrifood system is not available, a general estimate of the unmet financing needs of smallholder farmers is $170 billion annually and $106 billion for agricultural small and medium enterprises (ISF Advisors 2022, cited in Chiriac, Vishnumolakala, and Rosane 2023b).

5 Most of the data underlying the analysis by Chiriac, Vishnumolakala, and Rosane (2023a) is reported by development finance institutions and bilateral donors—thus, these trends may reflect that bias in the data collection.

FIGURE 10.3—SOURCES OF CLIMATE FINANCE BY GEOGRAPHIC DESTINATION, 2019–2020



Source: Chiriac, Vishnumolakala, Rosane (2023a).

Note: USD bn = billion US dollars.

DISCLAIMER: The designations employed and the presentation of material on this map do not imply the expression of any opinion whatsoever on the part of AKADEMIYA2063, the editors, and the authors.

agrifood systems (see section on “Barriers to leveraging climate finance for food systems” below), whereby public and philanthropic finance generally fills the gap left by commercial financial institutions that have little appetite for investments in agrifood systems due to high risks, low returns, and high transaction costs (Chiriac, Vishnumolakala, and Rosane 2023a).

One pathway to accelerate private investment in climate change adaptation is through developing the bioeconomy in African nations. Although we lack comprehensive data on how much finance and investment in African agrifood systems is directed toward the bioeconomy, Box 10.3 provides examples of untapped investment opportunities in this sector. By unlocking these investment opportunities, African countries can achieve a more sustainable and climate-resilient agrifood system.

In sum, as our analysis underscores, existing finance flows for climate-related action in African agrifood systems fall significantly short, particularly in meeting adaptation requirements. Addressing that deficit demands concerted efforts from all stakeholders, encompassing both public and private sectors, to ramp up funding for the climate needs of African agrifood systems. In the next section, we delve into the obstacles hindering increased investment in climate-related action, with a particular focus on adaptation. In the section on “Opportunities for financing” below, we explore innovative financing mechanisms capable of augmenting both public and private funding for agrifood systems.

Barriers to Leveraging Climate Finance for Food Systems

Scaling finance for food systems in Africa is hampered by a number of barriers. While some of these obstacles are typical of climate finance, others are inherent to the agrifood sector. Broadly, we can categorize barriers to increasing public and private investment in food systems adaptation in Africa as 1) structural and financial, 2) institutional and governance, and 3) technical.

Structural and Financial Barriers

Many African countries struggle to allocate adequate domestic funds for food systems adaptation. Their governments face significant challenges related to debt burdens, limited tax bases, borrowing capacity, and budget constraints while dealing with competing development priorities. These factors, combined with higher government borrowing costs amid rising global interest rates, create significant challenges in mobilizing public finance to address critical climate finance demands (Li, Natalucci, and Ananthakrishnan 2022). Furthermore, governments

BOX 10.3—UNTAPPED INVESTMENT OPPORTUNITIES IN THE BIOECONOMY

A sustainable and circular bioeconomy offers promising avenues for climate change adaptation in the agrifood sector in Africa. The following are examples of untapped investment opportunities:

- Regenerative agricultural technologies that promote soil health and fertility and improve water retention capacity
- Development and distribution of climate-smart crop varieties
- Development and distribution of biofertilizers, biopesticides, and bioremediation technologies that help increase agricultural productivity and resilience while supporting ecosystem restoration and carbon sequestration
- Sustainable development of tree-based systems, including agroforestry, which increase forest health and prevent soil erosion
- Development and distribution of new food sources (such as seaweed, microalgae, edible insects, cell culture–based food products, plant-based protein alternatives, and 3-D printed food) that can support food security goals while reducing input, energy, and water intensity
- Development and distribution of bio-based technologies for improved waste management, such as conversion of organic waste into compost and renewable fuels (Gomez San Juan, Harnett, and Albinelli 2022; Malabo Montpellier Panel 2022b)

Despite the potential of bioeconomy and nature-based solutions to yield both economic and environmental benefits, private capital investment remains limited because of the perceived or real risks associated with such projects. However, the growing track record of success in private sector forestry investments offers a potential model to bridge this financing gap (Throp et al. 2023). Demonstrating market viability—for instance, by showcasing established products, producers, and buyers and addressing challenges faced by bioeconomy businesses, such as regulatory hurdles or lack of certification—can also help reduce perceived risks and build investor confidence in bioeconomy investments. In addition, the application of distributed ledger technologies (for example, blockchain) for enhancing supply chain traceability, certification, and risk mitigation can reduce administrative burdens and create a level playing field for small-scale producers. Last, implementing pilot programs and exploring blended finance solutions can further mitigate risks and attract the requisite volumes of private investment (Leoussis and Brzezicka 2017; van Pul, Valladares, and Wolfs 2023).

often require initial capital to secure cofinancing from other sources or to establish new financial instruments for adaptation purposes, but such funds are not always readily available (Malabo Montpellier Panel 2022a).

Smallholder farmers and agricultural small and medium enterprises (agri-SMEs), in particular, face significant investment constraints in adaptation efforts, partly due to their limited financial capabilities. These actors struggle to cover the initial investment costs and have limited access to financial services. The constraint to access is due to greater transaction costs for investors associated with geographically dispersed customers; small ticket sizes; loosely structured value chains; high perceived environmental, productivity, and market risks; and high interest rates. In Africa, less than 3 percent of all financial credit goes to agriculture, and interest rates can be as high as 47 percent (Malabo Montpellier Panel 2022a). Furthermore, the localized and often small-scale nature of adaptation projects and concerns about scalability further deter investors (Micale, Tonkonogy, and Mazza 2018).

A lack of collateral and limited land tenure rights limit farmers' ability to secure financing. The very small size of smallholdings also means that the value of the land may not provide sufficient collateral cover for commercial loans. Gender disparities in ownership and access to resources, including land titles and land rights and technology, coupled with sociocultural barriers are a challenge for female farmers, reducing their ability to access climate finance compared with male farmers and heightening their exposure to climate risks. In addition, gender inequality is evident in climate financing from development partners, with only 3 percent of climate-related official development assistance in 2021 having gender as a principal focus (Ibrahim et al. 2023).

Farmers often encounter discrepancies between their financial needs and the available market offerings. For instance, repayment schedules may not correspond to farmers' production cycles, the loan amounts offered are usually too low, and capital costs may be prohibitively high—especially when demanding long-term financing. The reliance on rainfed agriculture implies that, depending on the commodity, planting and harvesting seasons may occur only once a year, exposing farmers and investors to an elevated risk of loss as weather patterns become more irregular due to climate change. Furthermore, inadequate contractual regulations and enforcement expose offtake arrangements to risks such as side-selling (Chiriac and Naran 2020; Galbiati et al. 2023).[6] These factors, inherent to the agriculture sector, serve as significant impediments to financing food systems adaptation in Africa.

Uncertain risk–return profiles further complicate food systems adaptation investments in Africa. Such investments typically do not yield immediate financial returns and involve substantial upfront costs and uncertainties surrounding climate impacts (Adeniyi 2023b; Ahairwe et al. 2022; Micale et al. 2018). While adaptation projects offer long-term benefits, the longer horizons to generate revenues make them less attractive for market-rate investments. Moreover, the prolonged payback periods and heightened risks associated with investing in vulnerable communities are incongruent with the risk-averse nature of many private investors (Adeniyi 2023a). Seasonal variations in agricultural cash flows, compounded by climate variability, exacerbate challenges for both producers and finance providers, increasing the risk of default. These factors collectively make food systems adaptation projects often "unbankable," prompting financial institutions to hesitate in funding such initiatives. This is in contrast to some mitigation initiatives, such as those related to forestry, which often provide more predictable revenue streams (for example, earnings from the sale of carbon credits or harvested biomass) and hence appeal to commercial investors. Such projects often have shorter payback times and clearer revenue pathways, which increase their attractiveness for finance (Chiriac, Vishnumolakala, and Rosane 2023a). Thus, the potential exists to leverage investments in bioeconomy projects that offer both climate adaptation and mitigation benefits for agrifood systems, including investments in carbon sequestration, soil health improvements, and cultivation of climate-resilient crop varieties.

Institutional and Governance Barriers

Investments in food systems adaptation in Africa are also constrained by governance and institutional bottlenecks. Many African countries lack the requisite legislation and regulations to accelerate finance for food systems adaptation, and where such policies exist, their effectiveness is limited by inadequate oversight and institutional coordination. Policy constraints range from a lack of explicit policies encouraging intersectoral collaboration to a lack of an enabling environment supportive of private investment. The presence of regulatory risks, including the functioning of the regulatory environment and potential changes in response to climate change such as subsidy reform, carbon tax implementation, and permitting processes, can deter climate investment (Adhikari and Chalkasra 2023). Private investors require coordinated institutional arrangements and investment environments characterized by regulatory and political stability, enforceable laws, and the protection of property rights (Micale et al. 2018; Tall et al. 2021).

The absence of coherent adaptation regulations, policies, plans, budgets, and investment plans is a deterrent for potential private investors in food systems adaptation. A mere one-third of African countries have formally submitted their NAPs. Furthermore, only about half of African nations possess a favorable environment for adaptation investments, as evidenced by their good performance in governance and planning elements, including institutional arrangements, the development of sectoral plans, estimation of finance needs, integration of adaptation with disaster risk reduction initiatives, and monitoring and evaluation of adaptation objectives (Eichhorn et al. 2023). For instance, Angola has provided cost estimates for adaptation action by sector and type of commitment (conditional and unconditional) and has further outlined specific strategies for mobilizing the required resources, and Kenya has effectively developed an integrated measuring, reporting, and verification (MRV) system, as well as integrated MRV tools for adaptation action (Eichhorn et al. 2023).

Furthermore, challenges in multilevel coordination result in gaps and inefficiencies in agrifood systems adaptation finance for Africa. At the international level, coordination among donors, implementing agencies, and DFIs is difficult because they often "speak different languages" and have different processes and interests (Karaki and Bilal 2022). The different global climate funds have diverse eligibility criteria, methods, and modalities, which have proven difficult to navigate for institutions involved in supporting food systems adaptation (Le Houérou 2023). In addition, aligning international climate funds with national priorities and strategies is often problematic, manifesting as a mismatch between donor agendas and the climate finance needs of recipient nations (Iacobuta et al.

6 Offtake arrangements refer to contracts where a buyer agrees to purchase future production from a seller. Side-selling occurs when the seller breaches the contract by selling the goods to a different buyer, often for a higher price.

2022; Qi and Qian 2023). At the national level, there is inadequate coordination among sectoral ministries, departments, and agencies, as well as between national and subnational governments, to collectively respond to the need to harness resources for food systems adaptation (Bellali et al. 2018). In Kenya, for instance, budget codes for climate-related expenses are not synchronized between national and local levels, making it difficult to track climate expenditures (Adeniyi 2023a).

Public–private sector partnerships can stimulate private capital investment for food systems adaptation in Africa. Similarly, collaborations among donors, DFIs, public development banks (PDBs), civil society, and local actors are required to catalyze private sector investment in food systems adaptation. Such partnerships, however, are underused, creating a gap in the effort to finance food systems adaptation using private capital.

Technical Barriers

The complexity of requirements to access many climate funds demands a level of capacity that is not always available at the national and subnational levels in Africa, limiting access to funding. Securing climate funding entails gathering technical information, conducting climate vulnerability and risk assessments, and preparing detailed analyses. However, national and local governments often face human resource and expertise constraints, which limits their ability to prepare such applications effectively (Adeniyi 2023a; Restle-Steinert et al. 2019; Rossi, Gancheva, and O'Brien 2017). Moreover, national strategies, such as NAPs, often lack adequate specificity and concrete project pipelines (OECD 2023).

In addition, meeting the stringent accreditation standards set by funds such as the Green Climate Fund (GCF) proves challenging, often requiring reliance on international entities (Soanes et al. 2017). The GCF, the world's largest fund dedicated to helping countries respond to climate change, created the Enhancing Direct Access program in 2015 to facilitate access for local organizations and to promote stakeholder-driven programmatic approaches to climate financing. However, because of the stringent criteria and perceived intensity and scope of the submissions and audits, few proposals are actually submitted (Tietjen, Rampa, and Knaepen 2019). Although the GCF is on schedule to allocate its adaptation-related funding following the priorities it has established in terms of country groups, disparities in access favor those with better institutional capacity—that is, middle-income countries (Garschagen and Doshi 2022). The GCF's slow and cumbersome proposal processes prevent many countries, primarily least developed countries in Africa and nations with weak capacity and with the highest levels of climate vulnerability, from sufficiently accessing project funding. In addition, many countries are currently not able to independently access project funds through their national entities, thus inhibiting direct access and country ownership (Garschagen and Doshi 2022).

There is also a lack of understanding of the risks and opportunities associated with climate change in many African countries, which is often due to the complexity of making disaggregated, reliable, and comprehensive data and information on climate risks and vulnerability available (Clark, Reed, and Sunderland 2018; Chirian and Naran 2020; Micale et al. 2018; Prasad et al. 2022; Restle-Steinert et al. 2019; Tall et al. 2021). There are also significant uncertainties regarding the future implications of climate change, socioeconomic considerations, population and migration trends, and policy and behavioral shifts (OECD 2023; Restle-Steinert et al. 2019; Tall et al. 2021). This lack of granular data impedes investment decision-making, making it challenging to invest in climate actions in food systems (Adeniyi 2023b; Restle-Steinert et al. 2019).

At the local level, many actors, including small businesses, SMEs, and smallholders, often lack the technical capacity to analyze climate risks, conduct feasibility studies, and identify climate-resilient investment opportunities. Small-scale producers fail to engage with climate-smart practices due to a lack of knowledge and financial incentives. Moreover, there is often a shortage of local expertise available to assist these actors, further limiting their ability to attract climate finance. Even when expertise is accessible, it tends to be temporary, with insufficient mechanisms in place to integrate the knowledge and skills into permanent structures, systems, and processes at the local level (Adeniyi 2023a).

Opportunities for Financing: Improved Mechanisms for Public and Private Finance for Food Systems Adaptation

In this section, we review the mechanisms and financial instruments that can be used to support sustainable and climate-resilient food systems. We discuss in particular the financial structuring process that leverages public and philanthropic capital to attract private investment in food systems adaptation. Additionally, we highlight instructive case studies, explore the challenges experienced and limitations to scale, draw key lessons, and assess opportunities to enhance and scale financing, with an emphasis on de-risking strategies and improving risk-return profiles to align the incentives of diverse capital providers.

Innovative Financing Mechanisms for Climate Action in Agrifood Systems

Transforming global food systems to become sustainable is essential to building climate resilience, protecting ecosystems and ensuring food security. The Food and Land Use Coalition estimates that the transition to sustainable food systems will require more than $300 billion annually, including $188 billion for smallholder farmers' inputs and mechanization (Apampa et al. 2021). However, IFPRI (2022) warns that "public financial resources, including multilateral development assistance, are not sufficient" to meet these needs. In addition, the bioeconomy offers significant potential to reduce GHG emissions along the agrifood system by replacing fossil-based resources and processes with biological ones, from microbiome innovations, biofertilizers, and biopesticides to new food sources, bio-based plastics and textiles, and biological waste management (Gomez San Juan, Harnett, and Albinelli 2022). This untapped potential can support both climate change mitigation and adaptation (see Boxes 10.1 and 10.3).

Historically, commercial banks and microfinance institutions have served as the primary sources of lending to the food and agriculture sector. A 2019 report by the United Nations Conference on Trade and Development (UNCTAD) notes that banks financed the sector to the tune of $700 billion annually between 2015 and 2017, while foreign direct investment contributed $36 billion, official development assistance provided $11 billion, and public capital expenditures amounted to $9 billion (UNCTAD 2019). While this picture represents global averages, the context in Africa south of the Sahara is different because commercial banks play a very limited role in lending to the food and agriculture sector (Prato, Clubb, and Rossman 2021). This trend has remained largely unchanged in the past decade; as Allen, Otchere, and Senbet (2011) point out, "a large number of banks shun private credit and instead invest in safer government securities, notably, treasury bills." Given the numerous sectoral risk factors, overall financing and funding flows have remained small relative to actual capital needs, leaving a considerable funding gap that is commercially unattractive for private investors. The major challenge, therefore, is to structure the food and agriculture sector so that it is both "bankable" and "investable" in order to attract larger volumes of financing and investments by catalyzing private investment (Apampa et al. 2021).

The global financial and capital markets comprise financial assets valued at $400 trillion. A small percentage of that value could readily finance the transition to sustainable agrifood systems and at the same time create positive environmental and social externalities. However, given the risk aversion and varying levels of risk appetite of these private investors, as well as their regulatory constraints and fiduciary obligations, it is clear that unless the market structure, business models, and the ensuing transactions along food and agricultural value chains are appropriately commercialized, the potential to scale private financing and investment will remain latent (Apampa et al. 2021). The challenge of attracting private financing and investment at scale is underpinned by (1) the compelling information asymmetries between investors and local actors; (2) high transaction costs driven by small financing needs and the overall small size of operations; (3) the informality of operators in the sector; (4) low levels of mechanization and technology use; (5) high volatility of commodity prices; (6) adverse macroeconomic conditions; and (7) political risks.

In Africa, value chain financing (from agro-dealers, off-takers, agro-service providers, and fintech companies) has been prominent in the recent past (ISF Advisors, Mastercard Foundation, and Rural and Agricultural Finance Learning Lab 2019 cited in SAFIN and Convergence 2021). Mobile service providers and agricultural and financial technology (agtech and fintech) companies have become increasingly significant lenders to the sector, particularly in East Africa.

Wattel and colleagues (2024) describe financial instruments that specifically target low-emission food systems, and that therefore directly contribute to GHG mitigation. These consist of investments made by financial institutions, investors, and public entities. Traditional financial instruments include debt (commercial and concessional), equity (commercial and concessional), credit enhancement through guarantee and insurance products, and fixed-income assets such as bonds. Such instruments can be structured with a purely commercial mandate with its attendant expectation to deliver attractive risk-adjusted returns, or they may pursue an impact mandate, or a combination of both. They can also be constructed as green finance[7] products that integrate environmental, social, and governance (ESG) considerations. For instance, sustainability-linked loans deliver both market-rate financial returns and economic returns for positive environmental and social outcomes. Demand for sustainability-linked loans is surging, especially in South Africa, which hosts the region's deepest capital markets (Fazel and Couzyn 2021). Notably, Rand Merchant Bank and Standard Bank have issued sustainability-linked loans valued at $450 million and $750 million, respectively (RMB 2024; Standard Bank Group 2023). These instruments and structured finance approaches are equally applicable to investments in the bioeconomy.

Wattel and colleagues (2024) further note how structured finance products can leverage the capital markets to "accelerate the low emission transition" in food systems. Institutional investors, made up of asset owners and asset managers, are increasingly cognizant of the importance of incorporating ESG guidelines in their investment portfolios, with many seeking to make responsible investments and signing up to various conventions. Accordingly, they are becoming more sophisticated in screening various asset classes through an ESG lens to ensure that their investment portfolios are green. This has resulted in the emergence of more green bonds and green investment funds that are mobilizing capital to support more resilient food systems while providing capital for smallholder farmers, processors, agribusinesses, and other value chain actors.

Carbon credits are also becoming more prominent at the production stage through the voluntary carbon market, where entities pay agricultural producers and supply chain companies for their activities and operations that help to eliminate or reduce carbon emissions. Consumers are also playing their part by accepting price premiums for sustainable and climate-friendly products, as well as interest discounts on climate investments (World Bank 2021).

Green finance practitioners could be local, regional, or national producers or producer communities investing in projects that have a positive impact on the environment. Green loans and bonds are useful throughout the supply chain, such as in primary production (comprising inputs, equipment, and service providers) as well as in postproduction (comprising trading, stocking, and processing). Such investments are targeted to generate environmental benefits. Green loans for climate-smart agriculture, sustainable agriculture, sustainable supply chain solutions, and waste management, in particular, are gaining prominence. However, for smallholder farmers and small agri-SMEs, green finance remains an elusive financing option, given their difficulties accessing credit from financial institutions. Their recourse is that they are invariably indirect beneficiaries, where large companies who leverage the green finance market create inclusive, green supply chains that benefit from the green conditionality.

Grants and public sector debt remain the primary instruments used to finance agriculture, forestry, and land use given the high perceived (and real) risks associated with the sector, as previously highlighted. Blended finance, a s financial structuring approach that leverages concessional capital from public and philanthropic sources to de-risk transactions and improve their risk –return profiles to attract private investment, is becoming mainstream as a lever to crowd in private capital. According to Convergence (2021), blended finance has become an important instrument to support the 2030 Agenda for Sustainable Development and agriculture-focused transactions accounted for 28 percent of the total blended finance market in 2020, a marked increase from only 16 percent in 2015–2017.

Food supply chains are global and are vulnerable not only to climate change but also to macroeconomic shocks, as seen in recent years with the global COVID-19 pandemic and Russia's invasion of Ukraine and the subsequent rise in food and fertilizer prices, which had knock-on destabilization effects. Minimizing vulnerability to these shocks requires innovative approaches, such as diversity in supply nodes, incorporating redundancy, "just-in-time" inventory, and alternate sources of financing. To build climate resilience, supply chain partners can offer favorable financing terms to suppliers who are aligned with agreed-upon sustainability targets, while helping food value chain companies incorporate ESG into their operations.

Insurance reassures investors that they can recoup their investment if unforeseen events occur, such as the adverse impacts of climate change. It therefore minimizes the risks associated with investing in sustainable food systems and further provides downside protection to investors. Insurance, as a tool, can thereby facilitate the transition to sustainable food and agriculture and land use

7 *Green finance* is a subset of sustainable finance and involves debt and equity instruments that seek to create positive environmental externalities.

practices, while managing price volatilities and yield risks related to climate change. Responsive insurance products are therefore an important instrument in building resilient food systems. Rectifying the low penetration of agricultural insurance in Africa is a compelling opportunity to achieve food security. Many African smallholder farmers remain vulnerable due to the wide variance in coverage, although their greatest risks are weather variability and the adverse impacts of climate change (Africa Insurance Organisation 2023, cited in Jimenez-Sanchez 2023).

Blended Finance for Agrifood Systems: Lessons Learned and Best Practices

Despite a staggering $379 trillion in global financial assets, only 4 percent are invested in developing countries, primarily due to the speculative sovereign risk ratings of their economies. Notably, a scant 11 percent of these countries are classified as investment grade (S&P equivalent of BBB or better), and of those, only two are in Africa— Botswana and Mauritius. Because no corporate entity or transaction can be rated higher than the sovereign due to political risk, innovative approaches, such as those deployed through blended finance, are useful in improving the "investability" of developing countries in general and of "risky" sectors such as those that underpin food systems and the bioeconomy. Blended finance is a useful approach that also helps address the constraints faced by regulated financial institutions, such as banks and insurance companies, which are restricted from lending to risky market segments where the high expected losses far exceed their investment mandates and criteria (Apampa et al. 2021).

The application of blended finance in the food and agriculture sector in particular seeks to de-risk transactions, but it also focuses on reducing the overall transaction costs to create more headroom for acceptable risk-adjusted returns (Prato, Clubb, and Rossman 2021). Apampa et al. (2021) identified four factors that contribute to the current sustainable food systems funding gap: "(1) high country and sector specific risks, (2) poor primary data and information asymmetries between financial institutions and potential borrowers in rural financial markets, (3) the mismatch between investment needs of farmers and producing companies and different pools of capital, e.g. development finance institutions, banks, pension funds, insurance capital, and (4) high transaction costs and small ticket sizes." These constraints result in an insufficient pipeline of bankable projects to attract financial institutions. Despite the vast environmental and social benefits that could be unlocked by transitioning the food system to more sustainable practices, the transition could lead to unacceptable financial losses for institutions.

Table 10.1 summarizes the diverse risk sources that discourage private investment, which are instructive for structuring commercially viable food system transactions that can deliver environmental benefits, promote food security, and provide attractive risk-adjusted returns.

TABLE 10.1—TYPES OF RISK HINDERING PRIVATE INVESTMENT IN AGRIFOOD SYSTEMS

Project/firm level risks	Constraints in financial absorption capacity	Country risks
Business risks: New untested business models or transition risks related to sustainability	**Informal sector:** New untested business models or transition risks related to sustainability	**Macroeconomic risks:** Global emerging markets risk, geopolitical risks, supply chain vulnerability, fiscal constraints, inflation, etc.
Agronomical risks: Unpredictable farm output and revenue due to unsustainable agroeconomic practices that affect product quality/quantity	**Lack of conventional security for lenders:** Limited or lack of collateral available to lenders, especially in jurisdictions where land rights are not well established	**Policy risks:** Limited domestic policy capacity in relation to food systems (domestic support, trade policies, infrastructure policy, etc.)
Natural hazards: High exposure to increased frequency and intensity of extreme climate events in the form of droughts, wildfires, hurricanes, and floods, etc.	**Small ticket size:** The average ticket size for agribusiness loans is small (compared to other industries)	**Political risks:** Domestic instability, political violence, lack of clear political leadership on sustainable development
Commodity market risks: Increased volatility of commodity prices, which affect costs, revenues and profitability	**Shallow domestic financial markets:** Local financial resources are undersupplied, and then only small amounts are available to food systems	**Inadequate enabling environment and regulatory capacity:** Insufficient capacity to institute and enforce regulations to enable sustainable finance

Source: Apampa et al. (2021).

BOX 10.4—THE CASE OF AGRI3 FUND

AGRI3 Fund is a blended finance fund that seeks to mobilize $1 billion in financing by providing credit enhancement and technical assistance investment projects and businesses to facilitate the transition to sustainable agricultural value chains, while minimizing deforestation. It serves to de-risk loans made by commercial banks and other financial institutions to agri-SMEs and projects that improve agricultural productivity, reforestation, and rural livelihoods. The fund extends guarantees to achieve this purpose.

As a financial structuring approach, blended finance can structure investments in resilient food systems transition through risk mitigation. The waterfall structure,[8] first-loss provisions, overcollateralization, and excess spread could create a risk buffer that provides protection (and comfort) to investors and financiers in the event of defaults leading to losses. Other risk mitigation measures could include letters of credit, cash collateral accounts, security bonds, guarantees, insurance, and credit derivatives, which serve as credit enhancement to also provide downside protection to lenders. Such instruments can all leverage concessional funding from public and philanthropic sources to crowd private commercial lenders into an otherwise risky sector. Box 10.4 provides a prime example of how blended finance can catalyze private investment in sustainable agriculture by providing credit enhancements and technical assistance to de-risk high-impact projects.

We emphasize that the ultimate objective of blended finance is to catalyze private investment at scale to close the Sustainable Development Goal (SDG) funding gap. Therefore, when considering what specific structuring approach to deploy to finance resilient food systems, it is critical to ascertain the commercial mandates, risk appetite, and financial return requirements of private investors to

BOX 10.5—THE CASE OF BUILD FUND MALAWI

BUILD Fund Malawi aims to end poverty and hunger by increasing investment in agriculture and other manufacturing and service supply chains, as well as increasing productivity within those supply chains through technology and innovation. It further seeks to achieve gender equality by supporting businesses where women are significantly represented in boards, management, staff, suppliers, or buyers. It aims to create 3,000 jobs (30 percent minimum for women and youth), integrate 75,000 small-scale producers into investees' supply chains, increase participating small-scale producers' income by 30 percent, expand fiscal space with aggregated income taxes of $19.3 million, and strengthen 15 supply chains.

BUILD Fund Malawi and the accompanying BUILDER Technical Assistance facility will support businesses with a combination of loans, equity, and technical assistance. BUILD Fund Malawi is a structured blended finance window of the BUILD Fund, managed by Bamboo Capital, with a target capitalization of $35 million. Through the BUILDER facility, technical assistance will be provided to businesses both before and after investment to improve the quality of their growth and SDG impact as well as reduce associated risks and costs.

The $35 million impact fund has a $15 million first-loss layer and a $20 million mezzanine tranche. It will employ senior loans, subordinated loans, and mezzanine equity ranging from $250,000 to $2.5 million to support projects in the target sectors. The average time frame for an investment is three years, but it can last up to eight. The fund has an estimated internal rate of return of 5 percent, and 21 projects have been preliminarily identified for due diligence and potential investment.

8 *Waterfall* describes how investment returns are distributed among investors. In simple terms, it determines and lays out the order in which profits are shared. *First loss* provides a risk buffer or layer of protection for investors in senior tranches, meaning that the first-loss capital absorbs the initial losses, and investors in the senior tranches are protected. *Overcollateralization* simply means that the value of collateral provided for a loan exceeds the value of the loan and reassures lenders that they will be able to recoup their principal in the event of a default.

BOX 10.6—THE CASE OF PASS TRUST

PASS (Private Agricultural Sector Support) Trust provides credit guarantee cover to local financial institutions to top up clients' collateral to help them become eligible for loans. Although other credit guarantee schemes exist in Tanzania, PASS Trust is the only one offering banks a guaranteed coverage ratio of 50 to 75 percent, with up to 80 percent for projects owned by women or youth. While other guarantee schemes offer better rates, PASS Trust remains competitive through its unique combination of business development and financial services, deposit of cash in partner banks, and swift response to claims. PASS Trust works with more than 15 commercial banks in the country. With its guarantee funds, it can attract other private sector funds for development objectives.

It provides credit guarantees across the agricultural value chain and offers different products, such as traditional guarantees, portfolio guarantees, and institutional guarantees. PASS Trust has forged close relationships with a range of stakeholders to establish blended donor funds (guarantees); sovereign guarantees (unfunded in the case of Sweden); commercial senior debt guarantees; portfolio guarantees and guarantees; commercial senior debt or private equity investments; and weather index insurance. At the beginning, the leverage with financial institutions was 1:1; in other words, for every loan it guaranteed, PASS Trust had to commit the full amount for which it had assumed risk. However, with increased financing from DANIDA and other donors, as well as a track record of paying claimed guarantees on time, its leverage had increased to 1:3 in 2018.

So far, PASS Trust's guaranteed loans have benefited more than a million agricultural entrepreneurs and created more than 2.5 million jobs. Because of the availability of guarantee funds, it also attracts private equity investors to its projects (usually from 20 to 40 percent, and in some cases up to 80 percent). It has also improved market access for farmers— for instance, by using blended finance models in contract farming and offtake agreements, as well as by deploying the tools across different value chains.

select the most effective instrument(s). For instance, beyond downside protection through risk mitigation, blended finance could also enhance the yields (risk-adjusted returns) associated with these investments. The transition to sustainable food systems that is based solely on commercial capital may otherwise not generate a sufficiently attractive financial return to raise the requisite capital.

Blended finance transactions generally create a higher leverage ratio (the number of private dollars mobilized as a result of using concessional dollars for de-risking) through aggregation in the form of funds and facilities that pool together resources. They provide diversification for investors (a risk mitigation approach) and exposure to diversified assets, investees, countries, regions, and sectors and are therefore a preferred investment approach that can also help to attract larger volumes of financing for building resilient food systems. In Box 10.5, we illustrate, as an example, how the BUILD Fund Malawi combines loans, equity, and technical assistance, impacting agricultural productivity and promoting gender equality through targeted investments.

Aggregating pools of capital through funds, facilities, and investment vehicles can increase the supply of financing for smallholder farmers, given the high transaction costs associated with single, small tickets for traditional lending. Credit facilities can be structured using blended finance with a diversified capital stack that provides first- (and in some cases second-) loss protection to investors in the senior tranches, or they can be structured using a portfolio approach in which all investors have the same risk–return profile. This is exemplified, for instance, in the PASS Trust in Tanzania, which uses credit guarantees to bolster local financial institutions' lending capacities and enhance agricultural finance access (see Box 10.6).

Another approach to attracting private investment for extending small-scale loans is through asset securitization. This involves repackaging portfolios of cash flow–producing financial instruments (for example, loans) into securities or tradable capital market instruments for transfer to other investors. Securitization essentially converts non-liquid assets into securities. In the context of building resilient food systems, the proceeds of asset-backed securities could be invested in sustainable food projects, and the structuring process could be funded through blended finance (for example, grants, technical assistance, and first-loss cover). Securitization can also benefit from "greening" by highlighting the positive environmental impact from the use of proceeds. This could be especially attractive as investors seek more ESG-aligned investment portfolios. Two other benefits of securitization for resilient food systems are (1) lower capital costs and (2) sustainable loans to food system value chain actors, beginning in the production phase.

Creating an Enabling Environment for Food Systems Adaptation Financing

Innovative financing mechanisms can play a crucial role in mobilizing funds for climate action in African agrifood systems, but they require an effective enabling environment. In this section, we discuss the three building blocks for creating such an environment.

Strengthening Coordination and Collaboration

Increasing the mobilization and deployment of climate finance for agrifood systems requires greater cooperation and collaboration among various types of actors (public and private) and at different levels (international, regional, national, and subnational). Better coordinating efforts of all actors can help prevent duplication, benefit from complementary knowledge and expertise, and maximize the impact of existing initiatives. As such, it helps optimize the use of available resources by designing new initiatives to address identified gaps, drawing from past successes and failures (Chiriac, Vishnumolakala, and Rosane 2023a).

In particular, stronger cooperation and greater synergies among development partners (for example, donors and development agencies), DFIs, and PDBs, as well as with local public and private actors and civil society networks, can foster the development of a pipeline of bankable projects anchored in the local contexts, which is key to catalyze transformative investments at scale and to transition to a green economy. An example of this approach is the Dutch Fund for Climate and Development, in which the Dutch PDB FMO works with the Netherlands Ministry of Foreign Affairs, the Dutch agency SNV, and other nonstate actors to implement investments in climate mitigation and adaptation. This cooperation provides an operational vehicle that spans the full investment life cycle, including project origination. A partnership approach can also help shift DFIs' focus from individual projects to portfolio approaches that encompass development and climate objectives, while facilitating investments (Karaki and Bilal 2022). Moreover, enhanced cooperation among DFIs can also help rationalize and harmonize taxonomies, policy conditionalities, and reporting requirements, thus reducing the fragmentation of financing approaches and easing the burden on recipient institutions to access finance (Ahairwe and Bilal 2023; Malabo Montpellier Panel 2022a). Such an alignment would also help provide higher amounts of cofinancing for adaptation projects in agrifood systems.

Effectively mobilizing and deploying climate finance also depends on using the right mix of financial instruments (Mustapha 2022). While different instruments are needed to cater to the diverse needs of financial intermediaries and agrifood companies at different stages of maturity or with different risk profiles, their coordinated deployment is necessary to maximize synergies and achieve impacts at scale. As such, a robust financial ecosystem that supports agrifood actors encompasses a combination of investors and financial instruments, as well as their linkages: from business incubators that support companies in the very early stages with grants or concessionary loans to impact investors, private financiers, and commercial banks that can provide debt finance or equity investments once the enterprises reach a commercial level (D'Alessandro, Rampa, and Dekeyser 2022).

Policy and Regulatory Frameworks

Addressing the financial gap for climate action in food systems, particularly for adaptation, also requires conducive policy and regulatory frameworks at the country and regional level.

First, there is a need to promote increased alignment of national climate and food policies to ensure coherence and consistency in objectives and implementation strategies (ECDPM 2023; Malabo Montpellier Panel 2022a). In particular, integrating agrifood system–related objectives (including nutrition) in NDCs and NAPs is key to effectively identify and prioritize adaptation actions and financing needs as well as track progress toward them (Malabo Montpellier Panel 2022a; Schulte et al. 2020). Alignment with regional strategies is also important: collaboration is needed to assess the regional distribution of climate finance flows and develop tailored strategies and interventions that address the unique challenges and priorities of each area (Galbiati et al. 2023).

Second, climate goals outlined in NDCs and NAPs should be translated into national and subnational investment strategies with a clear definition of the role of various players, particularly the private sector (Adeniyi, forthcoming), as well as an articulation of the needs, costs, incentive structures, and returns on investments (Malabo Montpellier Panel 2022a). This would support a more targeted deployment of climate finance toward the effective implementation of country-led plans that effectively involve local actors (Mustapha 2022).

In addition, it is essential to employ bottom-up and decentralized decision-making methodologies to guarantee that adaptation efforts effectively cater to the requirements and needs of the most vulnerable communities. This approach aids in pinpointing high-impact and urgently required actions while enhancing transparency and local ownership of interventions, thereby addressing structural inequalities (Adeniyi 2023a; Malabo Montpellier Panel 2022a).

Third, while African countries may not be able to provide as much domestic public climate finance as is necessary (given debt vulnerabilities and limited fiscal space available), they can optimize the use of the available national resources, not only by renewing efforts to meet the Malabo Declaration targets (Malabo Montpellier Panel 2022a) but also by revising public expenditure—including by repurposing subsidies to promote the adoption of climate-smart and regenerative farming practices and to promote systemwide resilience by embracing a transition to a bioeconomy (Chiriac, Vishnumolakala, and Rosane 2023a; Malabo Montpellier Panel 2022a, 2022b).

Fourth, African governments can step up efforts to mobilize private sector finance by reducing the costs of doing business, improving the investment environment, and deepening local capital markets, as well as by using policy and fiscal tools and market-based interventions to reduce project-related risks and incentivize private sector investment (Malabo Montpellier Panel 2022a). Private sector capital requires coordinated institutional arrangements and stable investment environments where investors can rely on governments to maintain regulatory stability, enforce laws, and protect property rights, including intellectual and physical assets. Effective regulations and political stability will be particularly important in attracting foreign direct investment and building investor trust (Micale et al. 2018; Tall et al. 2021).

At the same time, donors and DFIs must be less risk averse with their grants and other concessional finance instruments and provide incentives for domestic lenders to deliver more affordable borrowing prices for farmers and agrifood SMEs for investments in climate-resilient practices (Perera et al. 2023), including through more systematic use of blended finance and guarantees (D'Alessandro, Rampa, and Dekeyser 2022), for which there is growing evidence of their significant leveraging potential (Mustapha 2022).

Last, African governments should promote national policies that support investments in agrifood systems and improve rural financial intermediation, such as those that support savings mobilization, expand the range of available collateral substitutes, subsidize digital financial channels in rural areas for improved financial access, scale up agricultural risk management tools such as insurance protecting producers against droughts, or promote a more prominent role for national PDBs (D'Alessandro, Rampa, and Dekeyser 2022; ECDPM, IFAD, and CDP 2022). In addition, integrated solutions that encourage microfinance institutions to invest in and lend to farmers and agri-entrepreneurs can improve agrifood value chains by enabling investments in digital tools and climate adaptation practices (Ahairwe and Bilal 2022).

Capacity Strengthening, Data, and Evidence

Capacity strengthening and robust data and evidence are pivotal elements in fostering an enabling environment for bolstering the mobilization and deployment of climate finance within agrifood systems. In particular, enhancing the capabilities of national institutions to secure donor accreditation and access climate finance from multilateral institutions and global climate funds is imperative (Malabo Montpellier Panel 2022a).

Moreover, providing technical assistance and capacity-strengthening initiatives for local stakeholders, spanning from farmers to financial institutions and government agencies, can significantly enhance their proficiency in accessing and managing climate adaptation funds effectively. This support also aids in identifying and designing initiatives aligned with local adaptation objectives and developing feasible investment plans (Adeniyi, forthcoming).

Also, in the context of blended finance initiatives, technical assistance facilities that simultaneously support (1) the setup of the financial vehicles, (2) the capacity of local financial intermediaries, and (3) the capacity of the end beneficiaries to draw and implement viable business plans have a better chance of achieving tangible and lasting results. Technical assistance to the end beneficiaries, in particular, should go beyond access to finance and encompass a combination of services that support business growth and accelerate the development of investable opportunities. An example of this approach is provided by the Rural Kenya Financial Inclusion Facility, which combines a guarantee scheme and a debt instrument through which the International Fund for Agricultural Development invests $15 million to alleviate the liquidity constraints of nonbank financial institutions to stimulate green investments by smallholder farmers and micro-, small, and medium enterprises. The facility includes two technical assistance components, one targeting local financial intermediaries to help them expand agrilending activity and better monitor their portfolios, and the other targeting the clients/end beneficiaries (that is, agri-SMEs and smallholder farmers) with needs-based technical advice and financial literacy training (D'Alessandro, Adeniyi, and Rampa, forthcoming).

DFIs should also bolster their internal capacities to integrate climate and nature considerations into their portfolio of agrifood system investments. Simultaneously, local financial institutions should enhance their technical expertise in climate risks and relevant technologies for agrifood systems, ensuring effective adaptation and resilience strategies (Chiriac, Vishnumolakala, and Rosane 2023a). Adequate specialist knowledge is also necessary to handle technical aspects linked to the structuring of financial instruments in the agrifood sector (for example, on tenures and repayment cycles of loans and availability of collateral substitutes, but also on environmental and social sustainability criteria and operational modalities of blended finance more broadly) (D'Alessandro, Adeniyi, and Rampa, forthcoming).

In tandem with capacity building, the availability of comprehensive data and evidence is crucial for informed decision-making and efficient resource allocation. Systematic tracking and disclosure of climate-related financing flows should be improved to ensure transparency, accountability, and effective progress measurement (Chiriac, Vishnumolakala, and Rosane 2023a). This requires filling data gaps (especially for what concerns private sector financial flows) as well as harmonizing methodological and reporting inconsistencies at the domestic and international levels (GCA and CPI 2023).

Moreover, continued efforts to strengthen the business case for climate investments in agrifood systems are necessary to facilitate more and better climate finance flows within agrifood systems (Chiriac, Vishnumolakala, and Rosane 2023a). In the context of blended finance, in particular, more emphasis should be placed on progress monitoring and reporting to provide higher accountability and transparency of blended funds and enlarge the evidence base on their impact. This could be supported by better digitalization of the blended finance schemes procedures—for instance, by managing their disbursements and operations through digital platforms that facilitate online transactions as part of the scheme implementation while also generating data about progress and impact (D'Alessandro, Adeniyi, and Rampa, forthcoming).

Conclusion

Adaptation measures in agriculture and food systems are urgently needed to mitigate the adverse effects of climate change, reduce the continent's vulnerability to climate hazards, and foster the development of sustainable, resilient, and inclusive agrifood systems. Our analysis finds that current climate finance flows to agrifood systems fall significantly short of meeting Africa's requirements. The adaptation finance gap is particularly large when looking specifically at small-scale agrifood systems. Moreover, current climate finance flows inadequately address gender inequality and social exclusion. Addressing these shortfalls in funding demands concerted efforts from all stakeholders, encompassing both the public and private sectors, to ramp up funding for the climate finance needs of African agrifood systems.

Given the existing structural, institutional, and technical barriers currently constraining the effective mobilization and deployment of climate finance for agrifood systems at scale, this chapter explored innovative financing mechanisms that can fill the funding gap for climate action in African agrifood systems. It focused in particular on the application of blended finance instruments and their potential to catalyze private investment at scale by de-risking agrifood transactions or creating more attractive risk-adjusted returns that also deliver environmental and social benefits.

Our investigation reveals that the market structure, business models, and underlying sustainable food system transactions must align with the risk appetite and the regulatory constraints and fiduciary responsibilities of private investors in order to close the large funding gap. Efforts to increase overall climate finance toward building resilient food systems must therefore center on how best to commercialize the sector by improving its risk–return profile and better design financing mechanisms that are adaptable to the agrifood sector.

Fostering a conducive enabling environment is also essential for mobilizing and deploying climate finance at scale in African agrifood systems. That entails strengthening coordination among all stakeholders, crafting supportive policy frameworks, and prioritizing capacity building alongside robust data and evidence management.

CHAPTER 11

Just Energy Transition: Challenges and Low-Carbon Pathways for Africa

Smail Khennas and Youba Sokona

Introduction

Transitioning to renewable energy is a critical part of addressing climate change and ensuring sustainable development. However, if this transition does not consider the social, economic, and financial implications for African countries, it cannot be considered a "just" transition for Africa. At the social level, the transition to low-carbon pathways, such as renewable energy sources, will create new employment opportunities. However, poor countries and marginalized populations may face disproportionate challenges during this transition if they are excluded from decision-making processes or do not benefit from these new job prospects. It is therefore essential to ensure that low-carbon pathways help reduce social inequalities and improve livelihoods for people in these countries and communities. At the economic and financial levels, transitioning to low-carbon pathways will require significant funding to develop national or regional value chains, invest in research and development, and build capacity. International financial support will be crucial for developing countries, especially in Africa, to ensure a just transition.

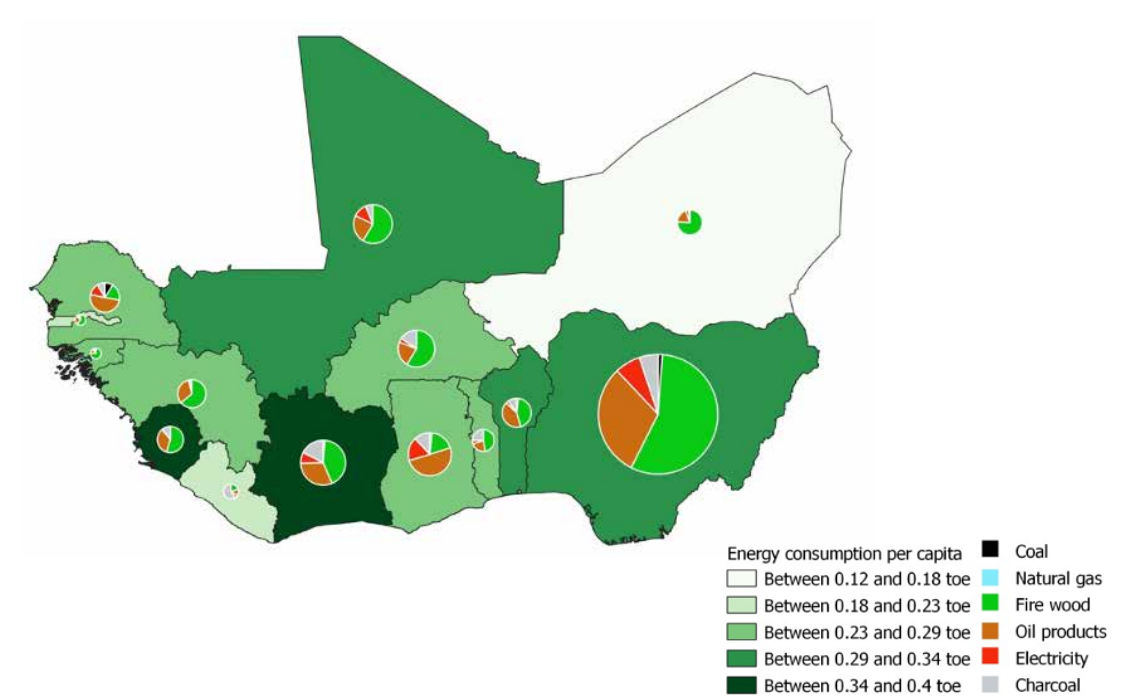
A just transition in Africa's energy sector is not just a matter of shifting from fossil fuels to renewables or low-carbon pathways; this transition must also promote social justice, economic development, and environmental sustainability, and strengthen Africa's place in the international division of labor and influence in global governance. In the global division of labor, African countries frequently act as suppliers of raw materials and low-value-added products, while wealthier nations or regions specialize in manufacturing and high-value-added sectors (Faizel 2021). This imbalance perpetuates economic dependency and limits the growth potential of African economies. To break this cycle, it is crucial to shift toward a more equitable low-carbon system that encourages industrialization, technology transfer, and capacity building within Africa.

The objective of this chapter is to review the existing evidence and debates on a just energy transition and low-carbon pathways in Africa, with the purpose of prompting discussions among researchers, policymakers, and practitioners.

Africa's Diversity: Common Challenges and Opportunities

The vast array of ecosystems across Africa—from the arid deserts of the Sahara to the lush rainforests of the Congo Basin—as well as unequal access to clean and efficient fuels and social disparities require tailored approaches to development and a just energy transition. Each region faces distinct challenges, such as varying levels of economic development and access to natural resources. For instance, North Africa, with its abundant solar energy potential, differs greatly

FIGURE 11.1—MAPPING FINAL ENERGY CONSUMPTION IN THE ECOWAS REGION IN 2021 (TOE/CAPITA)



Source: Khennas, Chitou, Kemausour, and Ramde (2024).
Note: toe = ton oil equivalent.

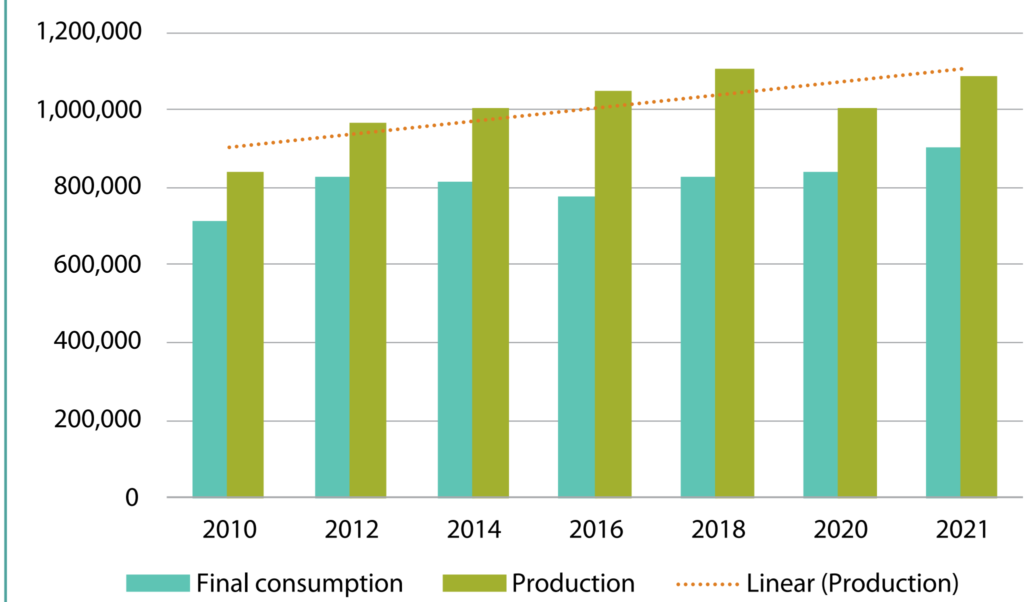
from the hydro-rich regions of Central Africa, the high potential for wind energy in some West African countries, or the geothermal resources of East Africa.

Moreover, socioeconomic development is a key determinant in shaping sustainable and equitable pathways to the energy transition toward cleaner renewable energy sources. Countries and regions have different levels of energy infrastructure and decision-making processes, which determine how they are impacted by the transition from fossil fuels to low-carbon economies. Countries such as South Africa and, to some extent, those in North Africa have more developed economies and infrastructure compared to many others in Africa, which significantly influences their capacity to implement energy transitions. Similarly, levels of technological adoption, governance structures, and public awareness vary widely across the continent, affecting the speed and nature of development initiatives.

Despite these differences, several key commonalities across Africa's regions unite the continent's approach to development and its energy transition. A significant portion of the African population relies on traditional biomass for cooking and heating, which poses severe health and environmental challenges. Indeed, most countries south of the Sahara still rely heavily on traditional and inefficient biomass fuels to meet their domestic energy needs for cooking and some productive activities. A recent study carried out by the Economic Community of West African States (ECOWAS) shows that in 2021, final energy consumption was dominated by biomass fuels (accounting for 60 percent), which included 51 percent for fuelwood and other biomass energy and 9 percent for charcoal (Khennas, Chitou, Kemausour, and Ramde 2024). Electricity accounted for only 7 percent of final energy consumption and petroleum products for 31 percent, indicating limited access to clean and renewable forms of energy.

Biomass (mainly fuelwood and charcoal) is the primary source of energy in most ECOWAS member states. Only Cabo Verde, Ghana, and Senegal have final energy consumption dominated by petroleum products. Moreover, Africa is the only continent experiencing a growth in firewood and charcoal production and consumption (Figure 11.2).

FIGURE 11.2—AFRICA'S BIOFUELS (FIREWOOD AND CHARCOAL) PRODUCTION AND FINAL CONSUMPTION, 2010–2021 (KILO TONS)



Source: Authors' calculations based on AFREC (2024).

The continent also faces a substantial gap in access to energy, with more than 600 million people lacking access to electricity, particularly in rural areas (IEA 2022). This creates a shared urgency to develop sustainable, affordable, and accessible energy solutions.

Another commonality is the continent's vulnerability to climate change, which exacerbates existing socioeconomic challenges. The impacts of climate change, such as extreme weather events, droughts, and floods, are felt across the continent, underscoring the need for a resilient and adaptive approach to development and an energy transition.

Toward a Just Energy Transition

Addressing these shared challenges requires a just energy transition that accounts for Africa's diversity while leveraging its communal strengths. A just energy transition in Africa must prioritize equitable access to energy, ensuring that poor countries and marginalized communities are not left behind. This involves not only expanding access to renewable energy but also creating economic opportunities through the development of value chains, such as manufacturing, in strategic fields, including critical minerals.

Regional and continental cooperation is crucial. Africa's diversity can be harnessed through shared initiatives, such as the African Continental Free Trade Area (AfCFTA), which aims to promote economic integration and collective growth. AfCFTA should provide a strategic platform for African countries to collaborate on large-scale energy projects, such as the Grand Inga Dam in the Democratic Republic of Congo, which could provide renewable energy to multiple countries. Through AfCFTA, African nations can present a united front in global discussions on climate change and energy, advocating for more favorable terms of trade, technology transfer, and financing to support a just energy transition. According to the World Bank (2020), trade will grow substantially within the continent by 2035. The volume of total exports is expected to increase by almost 29 percent by 2035 (relative to the 2020 baseline) and intracontinental exports by more than 81 percent, while exports to non-African countries will increase by 19 percent. The biggest expansion in exports to regional partners is expected in manufacturing. Cross-border energy projects, such as the West African Power Pool, demonstrate how regional cooperation can help optimize resources and improve energy access across multiple countries.

Convergence and Equity

The transition to a sustainable energy economy should serve as a catalyst for economic growth and social development. This will involve making use of the opportunities presented by emerging green industries, such as renewable energy, energy efficiency, and value chain development in key sectors including agriculture. The transition should create new economic opportunities, particularly in regions that are dependent on traditional energy sources, particularly in Africa south of the Sahara, where access to clean and modern energy remains very low, despite deployment of so-called sustainable initiatives and programs since the 1990s.

A just transition is fundamentally about ensuring that the shift toward sustainable energy systems is inclusive, fair, and equitable. The principles of convergence and equity are deeply interconnected in the context of a just energy transition. Achieving convergence without equity would likely exacerbate existing inequalities, leaving vulnerable populations and nations behind. Conversely, pursuing equity without convergence might result in fragmented efforts, undermining the global and systemic changes needed to effectively combat climate change.

Historical Responsibility

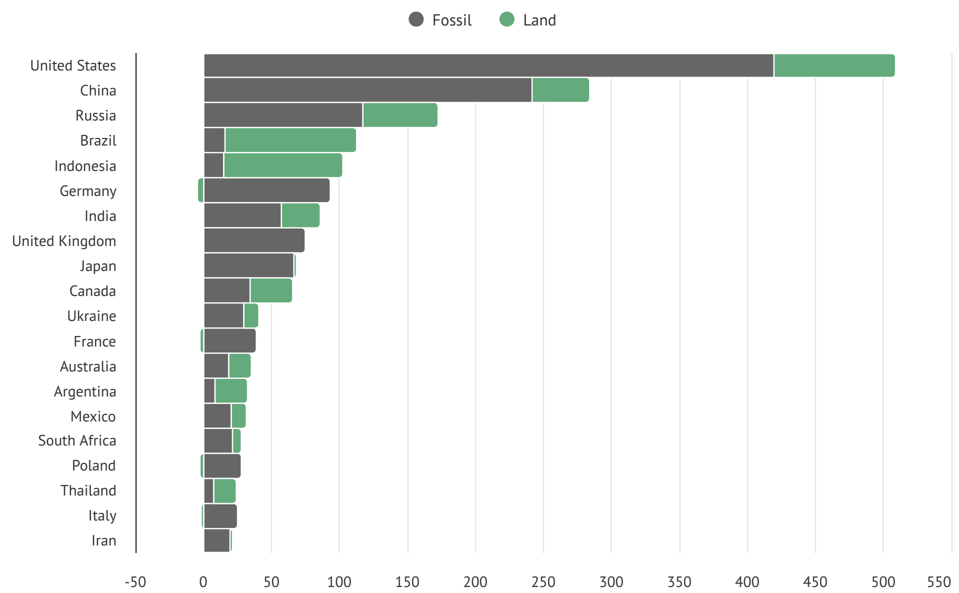
Developed countries have a significant responsibility to support a just energy transition globally, and particularly in Africa, given their historical contribution to greenhouse gas emissions and their relative wealth and technological advancement. Cumulative CO_2 matters because there is a direct linear relationship between the total amount of CO_2 released by human activity and the level of warming at the Earth's surface (Allen et al. 2009).

Wealthier nations and industries that have historically benefited from fossil fuels bear a greater responsibility to lead the transition to sustainable energy. This includes providing financial and technical support to developing countries, which are often more vulnerable to the impacts of climate change and less equipped to manage the transition. Historical responsibility also involves recognizing and addressing the injustices that have been perpetuated by the existing energy system, such as the exploitation of natural resources in developing countries and the displacement of Indigenous communities. A just transition requires that those who have contributed the most to environmental degradation take the lead in rectifying these harms and supporting a global shift toward sustainability.

Since the industrial revolution, approximately 2,500 Gt CO_2 have been released, contributing to the 1.2°C rise in global temperatures. This leaves fewer than 500 billion tonnes of CO_2 left to stay below a 1.5°C increase. By the end of 2021, the world used up 86–89 percent of this carbon budget. The United States is identified as the largest historical emitter, responsible for more than 509 billion tonnes, or 20 percent of the global total. China ranks second, contributing 11.4 percent of cumulative CO_2 emissions and approximately 0.1°C of global warming (Figure 11.3). Although China has consistently had significant land-related emissions, its current position is largely due to its rapid, coal-driven economic expansion since 2000 (Evans 2021).

The global shift toward cleaner renewable energy sources carries significant implications for emerging oil and gas producers in Africa south of the Sahara, including in countries such as Mozambique, Niger, and Senegal. Having recently

FIGURE 11.3—COUNTRIES WITH THE LARGEST CUMULATIVE EMISSIONS, 1850–2021



Source: Evans (2021).

discovered sizable hydrocarbon reserves, these countries are in the early stages of developing their oil and gas industries. However, the energy transition poses challenges to the long-term profitability of their resources, as global demand for fossil fuels is projected to decline in the coming decades. This could result in lower-than-anticipated revenues from their reserves. Economic diversification is becoming increasingly important. To reduce the risks linked to declining demand for fossil fuels, it is essential to focus on investing in sectors such as agriculture, manufacturing, and renewable energy. Such a strategy will contribute to reducing countries' dependence on volatile oil and gas revenues and foster more resilient, sustainable economies.

Additionally, during the transition phase, the development of oil and gas industries in these African countries can result in the establishment of essential infrastructure such as pipelines, refineries, and power plants, which can also benefit other sectors of the economy. For instance, industries such as steel, chemicals, and plastics heavily depend on refined products. Access to reliable, affordable energy enables industries to reduce operational costs and enhance productivity. The availability of energy encourages investment from other sectors, such as heavy industry and manufacturing, since energy-intensive processes can therefore be supported. The energy sector drives innovation in areas such as renewable energy, more efficient processing technologies, and energy storage. This will contribute to strengthening energy security and help mitigate the persistent energy shortages faced by many of these countries, thereby promoting industrialization and economic growth.

Transitioning to Low-Carbon Pathways: What is at Stake for African Countries

In the transition to green energy and sustainable low-carbon pathways, several critical issues must be addressed by African countries and their regional organizations, such as the Economic Communities.

Exacerbation of global inequities and geopolitics: Wealthier countries and regions may be better positioned to invest in and benefit from renewable energy technologies, while poorer countries may struggle to make the transition. This can exacerbate existing global inequalities and create new forms of energy imperialism, where rich nations dominate renewable energy production and control critical resources. The shift to renewables can also lead to new geopolitical tensions, particularly around the control of critical minerals and technologies essential for renewable energy and other key strategic sectors.

Concentration of ownership and profits: The benefits of renewable energy projects can be concentrated among large corporations from developed countries or, to some extent, emerging countries. For instance, apart from sourcing the key components for building renewable energy projects, large-scale solar or wind farms might be owned by multinational companies, with few dividends for African countries.

Unequal distribution of wealth: While renewable energy sectors do create jobs, these jobs may not be in the same locations or require the same skills as those in fossil fuel industries. Without targeted retraining programs and regional economic development, communities dependent on fossil fuel industries may be left behind.

Social and Environmental Concerns and Equity

Large-scale renewable energy projects, such as wind farms, solar panels, and hydroelectric dams, can require significant land use, which may lead to the displacement of communities or disruption of local ecosystems. Indigenous peoples and rural communities may be disproportionately affected if they are not adequately consulted or compensated.

The renewable energy sector relies on materials such as lithium, cobalt, and rare earth elements, which are often mined in conditions that raise serious human rights and environmental concerns. This can perpetuate cycles of exploitation and environmental degradation, particularly in resource-rich but economically vulnerable countries.

The Way Forward

Renewable energy is already cost-competitive compared to gas or other fossil fuels in many places. IRENA (2021) found that 62 percent of new renewables added in 2020 had lower costs than the cheapest new fossil fuel option. It also noted that two thirds of newly installed renewable power in 2021 had lower costs than the cheapest fossil-fuel fired option in the G20. Recent research by Way and colleagues (2022) concluded that "compared to continuing with a fossil fuel-based system, a rapid green energy transition will likely result in overall net savings of many trillions of dollars—even without accounting for climate damages or co-benefits of climate policy" (2057).

Africa's economy has historically been reliant on the export of raw materials with little value addition, which limits its benefits from global trade. According to the African Development Bank, the continent is at the bottom of the global value chain, with its share of global manufacturing at around only 1.9 percent (AfDB 2017). By investing in industrialization, Africa can shift toward processing and manufacturing its raw materials, thereby increasing the value of its exports.

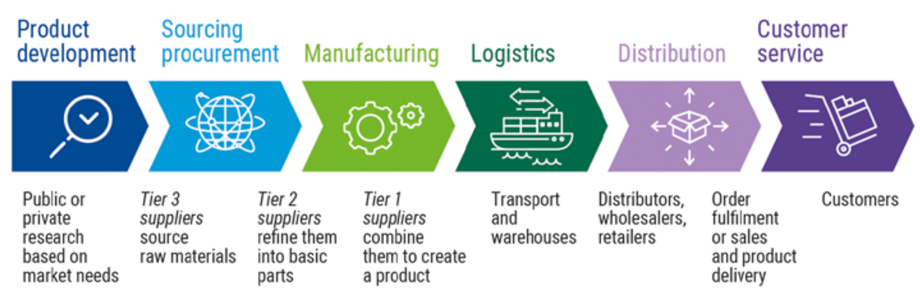
Potential For Capturing High-Value Supply Chains

To increase Africa's added value in the green energy sector, the continent needs to focus on attracting significant investment in renewable energy development, building local manufacturing capabilities for green technologies, creating supportive policy frameworks, fostering partnerships with international institutions, and leveraging its abundant natural resources, such as solar, wind, and hydropower, to generate clean energy for domestic use and export markets, while also developing skills and expertise within the sector to create sustainable jobs. South Africa and a limited number of other countries, particularly in North Africa, have made significant strides in manufacturing green energy equipment locally, reducing dependence on imports and creating jobs.

Strengthening regional value chains within Africa will enhance the continent's integration into global supply chains. The AfCFTA can play a critical role in this by facilitating intra-African trade, harmonizing regulations, and reducing tariffs. Although some segments of the green energy value chain are already controlled by China and a limited number of developed countries, there is potential to manufacture many components of the supply chain locally. For instance, the assembly of a solar field must be performed on site, offering significant potential for local manufacturing. As many component inputs, such as ball joints, bearings, and cables, are used by other industries, these parts offer opportunities for already established companies to achieve lateral diversification of customers (UNCTAD 2023).

Promotion of small and medium-sized enterprises (SMEs): SMEs are the backbone of many economies and play a vital role in creating jobs and fostering innovation. Supporting SMEs through access to finance, capacity building, and market access can enhance Africa's economic resilience and global

FIGURE 11.4—SUPPLY CHAIN COMPONENTS

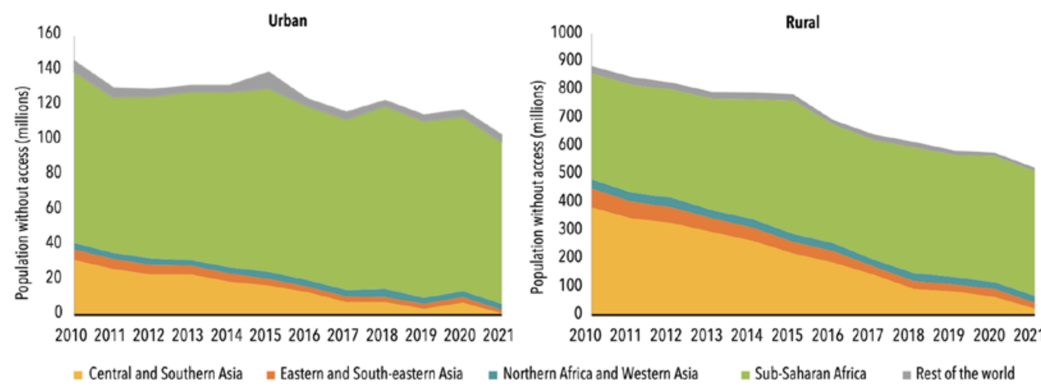


Source: UNCTAD (2023).

competitiveness. In Africa, SMEs provide an estimated 80 percent of jobs across the continent, representing an important driver of economic growth. Africa south of the Sahara alone has 44 million SMEs, almost all of which are micro enterprises (Runde, Savoy, and Staguhn 2021).

By contrast with the conventional approach to electrification—often referred to as "grid electrification" because it occurs primarily through extending the existing high- and medium-voltage grid—off-grid electrification, or "decentralized distributed generation," offers opportunities for SMEs to be involved in most segments of the off-grid electrification value chain.

FIGURE 11.5—DEFICITS IN ELECTRICITY ACCESS ACROSS URBAN AND RURAL AREAS, GLOBALLY AND IN SELECTED AFRICAN REGIONS



Source: IEA, IRENA, UNSD, World Bank, and WHO (2023).

Africa's Energy Systems and Opportunities for Off-Grid Deployment

In this chapter, off-grid electrification refers to renewable energy systems not connected to the centralized power grid. These systems can be standalone, serving a single or a few households, or part of a mini-grid supplying small communities or villages.

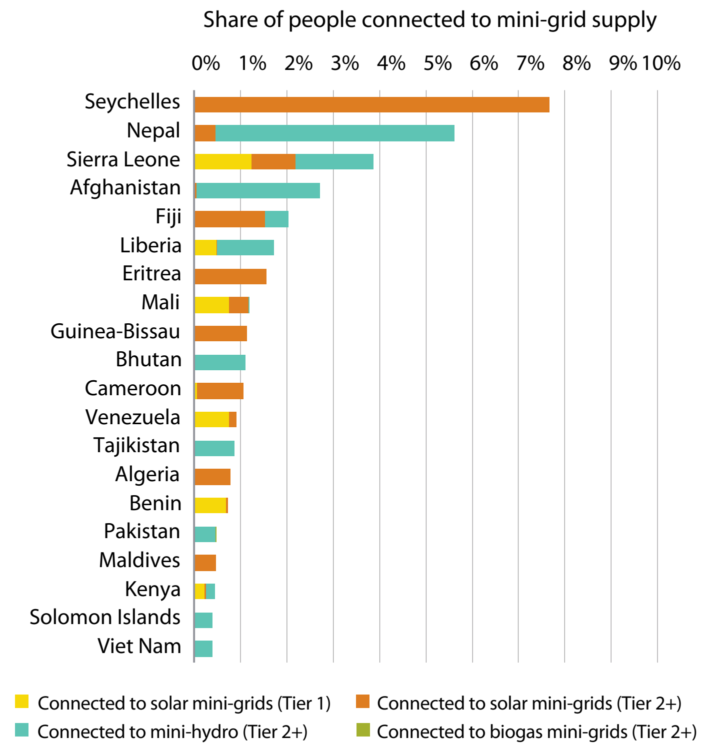
Energy system transitions require time and capital, particularly when energy infrastructure is either nonexistent (such as liquefied petroleum gas infrastructure or electricity distribution networks) or underdeveloped. A low- to zero-carbon energy development strategy will therefore require not only financial transfers but also, above all, a thriving manufacturing industry for energy to increase economic integration and a sustainable energy future for Africa's population. Almost all the literature on energy access in Africa highlights the lack of electricity access and the urban-rural divide. Indeed, this region still has the world's lowest rate of electrification and the highest population without access (Figure 11.5).

Figure 11.5 highlights the unequal access to electricity in Africa and the sharp rural-urban divide in Africa south of the Sahara. In many countries in this region, electricity access is below 46 percent and, in some cases, below 15 percent. According to the report by IEA and others (2023), the countries with the largest number of people without access in 2022 included Nigeria (86 million), the Democratic Republic of the Congo (76 million), and Ethiopia (55 million). Off-grid electrification offers opportunities to lower the costs of rural access to electricity, bridge the rural-urban gap, and provide opportunities for local manufacturers and service providers. Of the top 20 countries with extensive access to mini-grid electricity, nearly half are located in Africa south of the Sahara.

The current electrification system in Africa has been largely shaped by the classical traditional centralized power grid model, which is comprised of generation, transmission, and distribution. Large parts of rural and peri-urban Africa remain non-electrified, and current generation capacity is often unable to meet the demand from a rapidly growing population and proliferating micro, small, and medium enterprises. The supply-oriented approach characterizing the electrification system can hardly provide options and/or opportunities for widening electricity access to all populations in Africa south of the Sahara in the foreseeable future, if ever. Dependence on such a centralized power paradigm requires heavy investments and high operational costs. The shortcomings of such systems can hardly be handled by poor economies with limited capacities. Hence, Africa needs a new model.

Mini-grids already play a crucial role in helping countries achieve universal electricity access, particularly in regions that the national grid is unlikely to reach in the near future. Furthermore, mini-grids can be quickly deployed, creating local jobs and thus contributing to bridging the urban-rural divide.

FIGURE 11.6—SHARE OF POPULATION CONNECTED TO MINI-GRID SUPPLY



Source: IRENA (2022); IEA, IRENA, UNSD, World Bank, and WHO (2023).

Advances in technology and growing policy support further enhance their viability. In the countries where they operate, mini-grids outperform national utilities with respect to service metrics, including uptime, power quality, reliable connections, and downstream job creation. They have consistently high service uptime, on average above 99 percent, whereas national grids experience significantly more outages (SEforALL 2024).

The large-scale deployment of mini-grids has already drawn significant interest from African investors across the entire value chain. A notable example is the Africa Mini-grid Developers Association (AMDA), established by private mini-grid developers, operators, development partners, and investors to improve the political and financial landscape. Currently, AMDA represents more than 44 companies operating mini-grids in 22 countries across five regions of the continent (AMDA 2024). To accelerate mini-grid expansion and achieve universal access goals, AMDA has been working with policymakers to address key challenges, particularly regulation and the need for independently operated mini-grids to connect to the main grid. This would allow mini-grids to continue functioning by either selling power to or buying power from the main grid.

Unlocking financing for mini-grids in Africa is critical. The World Bank estimates that the 29,400 mini-grid projects currently planned—95 percent of which are in Africa and Southeast Asia—will require US$9 billion in funding (World Bank and ESMAP 2022). The two main financing models available are inadequate: larger deals with complex structures take too long to finalize, while smaller deals face high transaction costs. In this sector, there is a pressing need for concessional capital to de-risk financing to the level necessary to attract commercial investors.

Implementing Historical Responsibility

Developed countries have contributed disproportionately to global warming and are responsible for a significant portion of cumulative carbon emissions. To address the climate crisis, these countries must take responsibility for their contributions by playing a key role in driving global mitigation and adaptation pathways. This includes providing financial assistance, enhancing technology transfer, increasing ambition in emissions reductions, and compensating less developed countries for loss and damage. At the 15th session of the Conference of Parties (COP15) to the United Nations Framework Convention on Climate Change in Copenhagen in 2009, wealthy countries pledged to provide $100 billion per year in climate finance by 2020 to help developing countries mitigate and adapt to climate change.

Held in Paris in 2015, COP21 was a landmark in international cooperation, with developed countries agreeing to take the lead in reducing emissions and providing financial and technological support to developing countries. The Paris Agreement (UNFCC 2015), which resulted from COP21, also emphasized the need for technology transfer and capacity-building support from developed to developing countries. Wealthy countries are expected to share low-carbon technologies to help developing nations quickly advance to sustainable and low-carbon energy systems. At COP24 in Katowice in 2018, the Katowice Rulebook was adopted to operationalize the Paris Agreement, with a strong focus on technology transfer mechanisms. However, implementation has been slow, and many developing countries continue to call for greater access to climate-friendly technologies.

A key outcome of recent COPs, especially COP27 in 2022, was the landmark decision to establish a Loss and Damage Fund. This followed earlier milestones, including the creation of the Warsaw International Mechanism for Loss and Damage at COP19 (Warsaw, 2013), which was the first formal recognition of loss and damage within the UNFCCC. At COP26 (Glasgow, 2021), discussions on funding for loss and damage gained momentum, though no definitive financial mechanisms were agreed upon. However, at COP27 (Sharm El-Sheikh, 2022), a formal agreement to create the fund marked a breakthrough and was widely regarded as a historic achievement in global climate negotiations. The fund is intended to provide financial aid to vulnerable nations most severely impacted by the climate crisis, underscoring growing pressure on developed countries to acknowledge their historical responsibility and support those disproportionately affected by climate change. However, the structure and scale of the fund are still being negotiated.

Conclusion

Decentralized energy solutions such as mini-grids offer vital technical pathways for achieving a just energy transition, particularly in remote and underserved regions. These solutions are critical for providing sustainable modern clean energy, such as reliable electricity, in places where traditional grid extension is not cost-effective. However, the successful implementation and scalability of these solutions depend heavily on support from the international community and strong policy backing.

Moreover, regional integration across Africa plays a crucial role in maximizing the benefits of these decentralized energy solutions. By fostering cross-border energy cooperation, African nations can share resources, technical expertise, and infrastructure, which not only enhances energy security but also reduces costs. Integrated energy markets can help bridge the gap between energy supply and demand, ensuring that even poor countries and remote areas can benefit from reliable and affordable energy. This collaborative approach is essential for driving the continent toward a sustainable and inclusive energy future.

CHAPTER 12

Climate Action and Bioeconomy Transition: Mainstreaming Environmental Sustainability in the Post-Malabo Agenda of the Comprehensive Africa Agriculture Development Programme

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Introduction

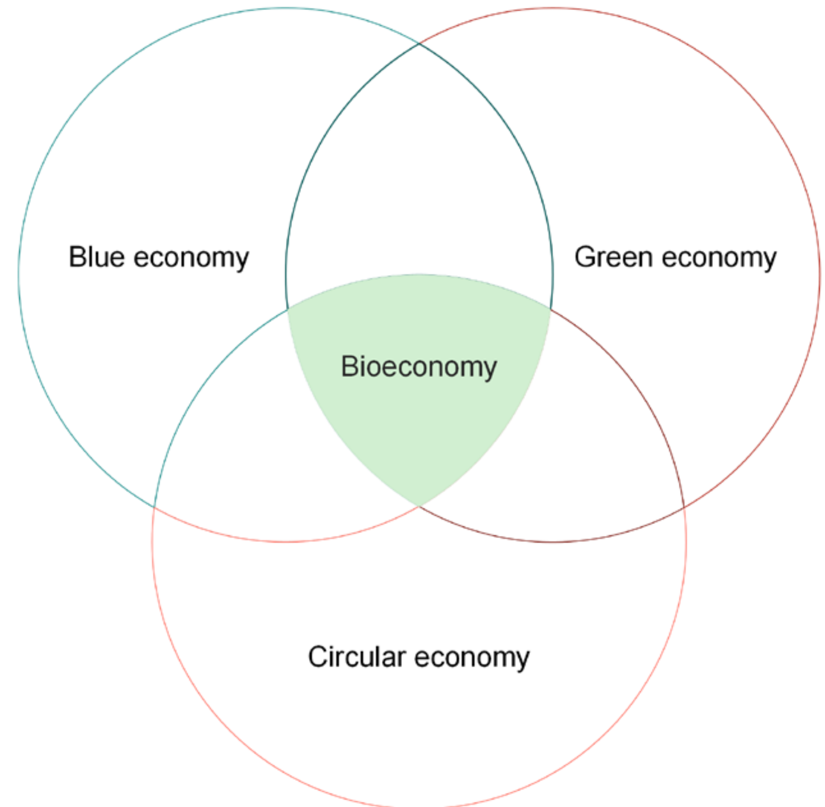
The concepts of the green economy, circular economy, blue economy, and bioeconomy started emerging in response to the multidimensional economic, socioecological, and climate change crises. These concepts are becoming popular in sustainability discussions in policy, scientific research, and business and are expected to promote sustainability through different pathways of transformation. Each of these frameworks offers a comprehensive package of solutions, yet all point toward renewable, bio-based processes and nature-based or nature-friendly solutions (Kirchherr, Reike, and Hekkert 2017; Geissdoerfer et al. 2017; D'Amato and Korhonen 2021). The bioeconomy, which is more focused on biological and nature-based/positive processes, is usually viewed as a more holistic concept that encompasses principles of the green economy, circular economy, and blue economy (Figure 12.1).

Green Economy

The concept of the green economy emerged from the 2008 financial crisis and was amplified by climate change challenges, which pushed the international community to advocate for redirecting public and private capital to finance green activities rather than the business-as-usual "brown" economy. This paradigm shift was strongly renewed at the Rio+20 conference in 2012 (UN 2012). Though highly context specific, the green economy encompasses all solutions that contribute to reducing carbon emissions and pollution, enhancing energy and resource efficiency, and preventing the loss of biodiversity and ecosystem services (Figure 12.1). The green economy, therefore, must be inclusive and result in improved human well-being and social equity while significantly reducing environmental risks and ecological scarcities. It is a low-carbon, resource-efficient, and socially inclusive economic model (UNEP 2011).

The green economy also enhances material and immaterial benefits from the biosphere (ecosystem services) to address human well-being, employment, and poverty alleviation while replacing fossil energy with abiotic renewable energy. Concrete actions are based on the assessment and accounting of ecosystem services, restoration and maintenance of ecosystems, and development of nature-based solutions and green infrastructure. Examples of success stories in agrifood systems include organic farming in Uganda, solar energy in food processing in Tunisia, and feed-in tariffs in Kenya (UNEP 2010).

FIGURE 12.1—INTEGRATED BIO-GREEN-BLUE-CIRCULAR ECONOMY FRAMEWORK



Source: Authors' analysis.

Circular Economy

The circular economy is defined in opposition to the dominant and prevailing global linear economy in terms of the physical flows of materials and energy; it aims to support the development of regenerative production/consumption systems, where inputs and outputs are minimized by slowing, closing, and narrowing material and energy loops. Its roots are in the ideas of industrial ecology and industrial ecosystems (Winans, Kendall, and Deng 2017; Kirchherr, Reike, and Hekkert 2017).

The concept of the circular economy is based on the principle that society and economy inevitably depend on the global biosphere. The thermodynamics of energy and material are recognized but conflict with the belief that full circularity is achievable. Temporal and spatial trade-offs between societal goals are acknowledged, but in practice, some undesired effects occur, such as energy leakage and rebound effects or inefficiencies (Gonçalves Castro et al. 2022).

The circular economy emphasizes improving material and energy performance, preferring product reuse and remanufacturing over traditional recycling and preferring product sharing and multifunctionality over ownership and monofunctionality. Circular economy solutions include a rethinking of product/service design to allow for efficiency gains; a reduction of material and energy needed for production; long-term maintenance; repair, sharing, reuse, refurbishing, remanufacturing, and repurposing; recycling and reclassification of waste into inorganic and biological components; and renewability of energy sources. In the agrifood sector, circular economy is used to optimize the food supply chain by using insects such as the black soldier fly (BSF) to transform vegetable and fruit processing byproducts into feed (BSF larvae) for poultry or fish (Nath et al. 2023) or into organic fertilizer (Beesigamuka, Subramanian, and Tanga 2022). Another example is cacao waste that can be transformed into many other products using circular economy processes. For example, cacao pod husks can be used as an alternative animal feed source (after processing to remove a harmful toxin), and they can also be converted to biochar as a potent compost, helping to improve soil quality by adding organic matter and enhancing soil structure, which promotes healthier crop growth (Ombelet et al. 2024). Other examples, such as insect-based organic fertilizers, may also be of interest to farmers (Makokha et al. 2023; Beesigamuka, Subramanian, and Tanga 2022).

Overall, the circular economy contributes to reducing inputs and outputs in production/consumption systems by retaining material and energy flows within high value/functionality levels for as long as possible, improving social conditions through job creation and regional development, and building resilience to climate change (Ellen MacArthur Foundation 2019; Geissdoerfer et al. 2017).

Bioeconomy

The bioeconomy leverages the potential of biological resources from land and sea for the development and commercialization of goods and services. It focuses on the use of biomass, with scientific knowledge and innovations driving this process (D'Amato and Korhonen 2021) of converting biomass into various products, from bioenergy and fuels to paper and commodities, textiles, chemicals, and pharmaceuticals. Bioeconomy products range from biomass-demanding, low-value products, such as biofuels, to high-value products requiring smaller biomass quantities, such as bio-based chemicals or compounds. The underlying principle of the bioeconomy is that it should be environmentally, socially, and economically sustainable. The bioeconomy has potential to replace lithosphere inputs (that is, fossils) with biosphere inputs (living biomass) in economic activities, thereby improving social conditions through job creation and regional development. The key actions are the development and marketization, through knowledge and technology, of innovative and high-value goods and services from the potential held in biological resources while ensuring sustainable sourcing and efficient resource use.

The International Advisory Council on the Global Bioeconomy (IACGB) currently defines the bioeconomy as "the production, use, conservation, and regeneration of biological resources to provide sustainable solutions (including information, products, processes, and services) in and across all economic sectors" (Ecuru, MacRae, and Lang 2022). The definition positions the bioeconomy as a cross-sectoral endeavor, which combines natural resources, scientific knowledge, and technologies with markets and business opportunities, as well as helping tackle societal challenges such as natural resource scarcity, waste generation, fossil fuel dependence, climate change, loss of biodiversity, and food and energy insecurity, all while achieving sustainable growth (Malabo Montpellier Panel 2022a). It further presents opportunities for climate mitigation through carbon sequestration in plant and forest matter and soils (referred to as carbon farming) and adaptation, particularly in Africa's agricultural sector.

The inclusion of the bioeconomy as one of 20 program priority areas in the Strategic Framework 2022–31 of the Food and Agriculture Organization of the United Nations is seen as a key policy boost to its global advancement (FAO 2021). An analysis by the IACGB of various policies and strategies around the world showed agreement among policymakers that the bioeconomy is contributing to climate neutrality, food and nutrition security, improved health, economic growth, and many other objectives aligned with sustainable development (IACGB, 2024; Makoni 2021; World Bank 2020b; Kamarulzaman and Mostapha 2020).

Toward an Integrated Framework

In an ideal scenario, the bioeconomy promotes economic growth and social progress while decoupling development goals from increasing resource consumption and greenhouse gas (GHG) emissions (Malabo Montpellier Panel 2022; Ochieng and Onyango 2021; World Bank 2020b). It is considered a transformative pathway to achieving the African Union Agenda 2063, as well as several Sustainable Development Goals (SDGs) (Teye and Owusu 2021; Badu and Boateng 2022) and other global agendas on climate (United Nations Framework Convention on Climate Change [UNFCCC]) and biodiversity (Convention on Biological Diversity), while embedding principles of circularity and sustainability in all the agenda setting processes. Therefore, it should be seen as a unifying, integrated, and cross-sectoral framework that offers numerous opportunities to cope with global challenges by providing technology-based innovations (Okafor 2021). Transitioning to a sustainable bioeconomy can be achieved by effectively merging green, circular, and bioeconomy models into an integrated framework leading to climate-smart actions, thereby accelerating sustainable development (Figure 12.1). Doing so will require more engagement of communities and more involvement of science and technology innovations throughout all processes (Mensah and Enu-Kwesi 2022; Poku and Birner 2022; Teye and Owusu 2021; Ochieng and Onyango 2021; Asafu-Adjaye and Mahama 2019).

According to the Malabo Montpellier Panel (2022), evidence in Africa shows that the bioeconomy can contribute to sustainable development through innovative and less-resource-intensive agricultural technologies, thus increasing food security while decreasing environmental degradation (SDGs 2, 13, and 15). By improving circularity and promoting biotechnological innovations, the bioeconomy can contribute to optimizing resource consumption, thereby minimizing waste (SDGs 6, 11, and 12). The conditions required to achieve these goals include large-scale investment in bio-based innovations and economic infrastructure, capacity development of entrepreneurs, awareness raising, incentives for market and non-market conditions (Mockshell et al. 2023; Piñeiro et al. 2020), and efforts to address socioeconomic and cultural challenges, including behavioral change (Yaro and Doku 2020; Okafor 2021; Adom and Amoako 2019).

Structure of the Chapter

The objective of this chapter is to review bioeconomy trends and the bioeconomy's potential contribution to integrating the blue economy, circular economy, and green economy for sustainable agrifood systems. It is structured in three main sections. The first section presents a review of the key formal governance frameworks at Africa's continental, regional, and national levels pertaining to climate change, food systems, and development agendas, with a view to identifying enablers and regulators that can facilitate the integrated bioeconomy, which is at the intersection of the blue economy, circular economy, and green economy. The second section focuses on the main constraints to implementing climate actions and expanding bioeconomy uptake, while the third section discusses implications for Africa's growth.

Bioeconomy Development in Africa

Policies are the primary enablers for developing sustainable bioeconomies in Africa. Though not explicitly designed to support the bioeconomy, most African agricultural and economic development policies have some enabling orientations and opportunities for the development of the bioeconomy across the continent. Some of these have been highlighted in the report titled *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy* (Malabo Montpellier Panel 2022a). This report leverages case studies and policy dialogues to show how Africa can develop sustainable bioeconomies that optimize social, economic, and environmental benefits and achieve societal prosperity. In this section, we summarize selected messages from that report and expand them based on new policies and criteria of analysis. We then focus on how the existing policies are supporting the critical driving forces of the bioeconomy, namely: (1) governance; (2) science, research, and innovation; (3) market and trade of bioproducts; (4) conservation of bioresources (preservation and sustainable use); (5) intellectual property; and (6) infrastructure development.

At the Continental Level

Opportunities for Bioeconomy Development in Agenda 2063

The African Union (AU) Agenda 2063 and its implementation instruments have created a solid foundation for the development of a fast-growing bioeconomy in the continent.

The fundamental principle of the bioeconomy is that it must be science-driven and sustainable. Aspiration 1 focuses on the governance of science, technology, and innovations, with Goal 2 underscoring the importance of education and skills revolution. This translated into the AU Science, Technology, and Innovation Strategy for Africa toward 2024. It is further connected to Goal 4 on the transformation of economies and job creation and to Goal 5 on modern agriculture for increased productivity and production. These goals are reflected in the Malabo commitments to stimulate agricultural growth in the continent, spanning finance, productivity, research, and sustainability (AUC 2014).

Through the Malabo Declaration (AUC 2014), AU member states committed to doubling agricultural productivity by 2025, yielding more biomass and an opportunity to trigger bioeconomy development and sustainable growth. This goal is further reflected in the promotion of agro-processing to halve postharvest losses for 5 to 11 AU priority commodities by 2025. Doing so facilitates the mainstreaming of bioeconomy principles and methods throughout the value chains, and is underpinned by increased access to finance, investment in research, and targets on sustainability in land and water management and water use.

Aspiration 1, Goal 7—which is related to the development of environmentally sustainable, climate-resilient economies and communities—aims for sustainable use of biological resources, management of natural resources, conservation of biodiversity, sustainable consumption and production patterns, improvements to water security, strengthened climate resilience and natural disaster preparedness and prevention, and an expansion of the provision of renewable energy, through the Green Recovery Action Plan (AUC 2021).

The Second Ten Year Implementation Plan (2023–2033) of Agenda 2063 recognizes the potential of biotechnology for sustainable food systems and industrial development. Biotechnology, as part of the bioeconomy, is expected to help transform seed systems and generate innovation, leading to safer and more nutritious food, industrial chemicals with fewer negative environmental impacts, and safer pharmaceuticals (AUC 2024b). The plan calls for increased investment in bioscience research and processes that enable the translation of these research outputs to innovation and business.

Opportunities for Bioeconomy Development in the AU's Climate Change and Resilient Development Strategy and Action Plan (2022–2032)

Policies, Institutions, and Legal Frameworks

The AU Climate Change and Resilient Development Strategy and Action Plan (AUC 2022) (abbreviated here as "the AU strategy") contributes to the implementation of Agenda 2063. It draws on the UNFCCC climate action pathways for resilient development and builds on Africa's efforts to achieve climate-resilient development pathways and accomplish the SDGs. The bioeconomy aligns well with its objectives and strategic intervention areas. The strategy recognizes that bio-based outputs are an indispensable component in the portfolio of low-carbon technologies that must be deployed to limit global warming to 2 degrees Celsius.

The AU strategy also clearly "seeks to enhance the adaptive capacities of Member States, and further seeks to promote low-emission growth pathways aligned with the 1.5-degree Paris Agreement goal and shaped by the principles of the green and circular economy, sustainable development, and poverty reduction" (AUC 2022, 6). The framework reinforces the need for a circular economy for sustainable development, systems, and value chain approaches; low-emissions industrialization; food systems transformation; and protection of land-based ecosystems, all of which are also consistent with bioeconomy principles. Three of the five top areas in food systems transformation (the priority area) promote (1) the enhancement of resilient food systems against climate effects while emphasizing nutrition outcomes and integrated planning, (2) the agroecological transition to reduce GHGs and dependencies on external inputs, and (3) stronger food system governance.

Specifically, the strategic intervention axis 1 (AUC 2022) focuses on strengthening policy and governance by enhancing inclusive, multiscalar governance and institutional coordination, including adopting a "whole-of-economy" approach; considering the processes and not just the outputs when developing strategies; mainstreaming low-emission development across all levels of policies, frameworks, and action plans; and promoting public–private partnerships. These are clear opportunities for using the bioeconomy to accelerate the implementation of this strategy.

Science, Research, and Innovation

The AU strategy emphasizes science, research, and innovation as the main pathway toward transformative climate-resilient development—that is, transforming food systems; protecting land-based ecosystems; transforming energy systems; enhancing inclusive, low-emission industrialization; transforming the blue economy; and achieving digital transformation. It refers to the extensive use of smart, innovative, and climate-resilient technologies, renewable energy production, breed/varietal development/switching, and technologies that preserve and enhance nutritional qualities in food. This requires thorough assessment and sustainable usage of biomass and bioresources to improve the productivity and quality of food products. The strategy also recognizes the importance of supporting research, extension, and implementation of public sector and market–based instruments toward agroecological, regenerative, nature-based, and Indigenous approaches for integrated farming and pastoral systems or resilient landscapes (practices to increase agrobiodiversity, conserve land and water, cycle nutrients, reduce waste, and enhance productivity). These are of particular interest in bioeconomy processes, for they infuse science, research, and innovation along food value chains, maximizing production, processing, marketing, and consumption sustainably while minimizing losses. Developing the bioeconomy, particularly for promising food value chains, will contribute to accelerating food systems resilience in an environmentally friendly manner while creating opportunities for industrial development, market segmentation, and sustainable green jobs adapted to youth and women.

Innovations and localization are critical to providing shared opportunities for climate resilience and the bioeconomy, particularly for technological transformation in energy, food systems, pharmaceuticals, information, and communication.

Conservation of Bioresources (Preservation and Sustainable Use)

The AU strategy further highlights the importance of an appropriate valuation framework for ecosystem services, the transition to more nature-positive production systems, and the development of "sustainable ecosystem–based approaches." The strategy aligns with the bioeconomy, which relies on healthy biodiverse and resilient ecosystems, the provision of ecosystem services, and the sustainable management of biological resources (plants, animals, microorganisms, and derived biomass, including organic waste) and the circular transformation of these into food, feed, energy, and biomaterials within the ecological boundaries of the ecosystems that it relies on (Palahí et al. 2020).

Nature offers more than 30 percent of the mitigation actions needed by 2030 to limit the worst effects of climate change through natural climate solutions. The bioeconomy aims to put the sustainable use of nature and natural resources at the heart of climate-smart solutions to reduce GHGs, avoiding further loss of nature and restoring important ecosystems.

Market and Trade of Bioproducts

Through the strategy for climate change and resilience, the African Union supports the development of market-based mechanisms to reward social and environmental outcomes (ecosystem outcome verification, bundling of ecosystem services with carbon markets for the agriculture sector, etc.), which is facilitated by the bioeconomy.

Priority Value Chains for Bioeconomy Development

The recent report on Africa's development dynamics (AUC/OECD 2022) in food systems transformation identified two major value chains at the continental level that have strong linkages with the bioeconomy. The first is the agro-industry, specifically for fruits and nuts, whose linkage to the bioeconomy relates to its large workforce competitive advantage in key cash crops (that is, cashews, coffee, cocoa), their predominance in the market and trade landscape in favorable regions, and the increased food demand driven by population growth and urbanization. This aligns well with the Fourth CAADP Biennial Review Report (AUC 2024a), which showed that levels of agro-processing are rising and need strengthening to boost entire value chains in the agricultural sector.

The second major value chain is pharmaceuticals, due to its strong political momentum and national initiatives to boost manufacturing development, such as in Ethiopia and Zimbabwe, as well as the international cooperation mechanisms through the WHO resolution of 2021 sponsored by all 54 African countries (AUC/OECD 2022).

These two major value chains (pharmaceuticals and agroindustry) are linked and can reinforce one another. An example is the development of the cocoa value chain in Ghana, which has involved the health system in using extracts as alternative treatments for health issues.

There are, however, specificities within each Regional Economic Community (REC) (AUC/OECD 2022): wood in Central Africa; coffee and floriculture in East Africa; date palm and energy production in North Africa; and poultry, cashew nuts, textile, aquaculture, and edible salt in West Africa.

At the Regional Level

The East Africa Community Vision 2050 and the East African Regional Bioeconomy Strategy 2021/22–2031/32

The East Africa Community (EAC) is a pioneer in strategically embracing the bioeconomy agenda in Africa through its dedicated regional bioeconomy strategy (EAC 2022). This strategy is anchored in the East Africa Community Vision 2050 (EAC 2016) and other regional science, research, and innovation frameworks. The region's Vision 2050 has strong pillars of development that include ensuring food security, manufacturing and industrialization, natural resource management, and promotion of green growth.

The regional bioeconomy strategy is rooted in a critical analysis of its potential for the transformation of bio-based sectors for sustainable economic growth and development as provided in the broader framework of the Vision 2050 and AU Agenda 2063. It posits that scientific research, knowledge, and innovation can be applied through the bioeconomy model to the production of food, feed, fiber, fuel, and a wide range of agro-industrial and value-added products. This leads to yet more added value of local bioresources by maximizing all parts of primary produce and their products sustainably.

The region's priority is economic growth based on both traditional and emerging industries using bioresources to create and develop new markets that can enable an increase in the entire economy's competitiveness. The strategy provides the guidance needed for the optimal production and value addition of bioresources to improve economic growth, create jobs, add more value to primary production, generate wealth, and connect smallholder farmers to new bio-based value chains, sustainable industrialization, and regional competitiveness.

The EAC strategy focuses on creating new or improved bio-based products that add value at the local level and use resources in novel, innovative, and sustainable ways. Specifically, it covers optimization and innovative use of biomass and biological resources from agriculture, aquaculture, bioprospecting, and forestry. The scope of the strategy covers alternative sources of food and feed, health and bioenergy services, and ecosystem services.

The objective of the first thematic area is to introduce new bio-based technologies and solutions to strengthen food and feed production, ensuring food security. The second is to develop a bio-based healthcare sector, contributing to a healthy population with improved well-being, addressing regional priorities, and building on Indigenous knowledge and practices. The third is to develop industries that stimulate sustainable economic growth and add value to underutilized renewable resources in the region to increase the production and use of sustainable bioenergy. The fourth is to develop a range of bioenergy products for both household and industrial purposes. The strategy provides opportunities for each member state to advance their bioeconomy in an area where they see a comparative advantage. Such territorial specialization would be facilitated by the African Continental Free Trade Area agreement that was signed by several member states in March 2018 in Kigali, Rwanda (World Bank 2020a).

To realize the promises of a modern bioeconomy, countries in the region need to develop national bioeconomy strategies with relevant detailed action plans. It appears necessary to set up a bioeconomy knowledge-sharing portal that provides a regional open-access repository for bioeconomy data and information (EAC 2022). Regional conferences and status reports will help increase stakeholder awareness and provide the latest scientific evidence on the status of the bioeconomy in the region.

Economic Community of West African States Regional Climate Strategy and Action Plan (2022–2030)

Toward Inclusive and Sustainable Development

Unlike the EAC, the Economic Community of West African States (ECOWAS) does not have a dedicated bioeconomy strategy. However, the framework in *Vision 2050—ECOWAS of the Peoples: Peace and Prosperity for All* (ECOWAS 2022b) features many driving forces relevant to mainstreaming the bioeconomy to accelerate the region's sustainable development. The vision focuses on inclusive and sustainable development, which can be fostered through harnessing appropriate innovations across different segments of the development process.

Specifically, Pillar 4 targets transformation and inclusive and sustainable development (ECOWAS 2022b). The goal is to make ECOWAS a regional economic power in Africa and the world that optimally utilizes its human and natural resources to improve the well-being of its citizens, as stipulated in the ECOWAS human capital development strategy. This pillar is therefore based on improving the population's living conditions by optimizing the benefits from economic growth resulting from changes to a population's age structure, quality of education and knowledge-building systems, creation of decent jobs for young people and women, and strengthening of resilience in public health. This pillar is also based on the structural transformation of economies driven by the digitalization of the economy, entrepreneurship, science and technology, and structuring investments in growth sectors. It aims to promote efficient management of natural resources and strengthen the region's resilience to climate change and exogenous shocks.

The *ECOWAS Regional Climate Strategy and Action Plan 2022–2030* (ECOWAS 2022a) covers a set of actions on strengthening environmental sustainability and climate change and on promoting sustainable economic growth and development, with a strong emphasis on economic transformation and industrialization, community enterprise development, promotion of innovations, quality products, value chain development, private sector development, public–private partnerships, and an improved business-enabling environment. All of these are key triggers of rapid bioeconomy growth in the region.

While the bioeconomy is not mentioned explicitly in the document, the blue and green economies are mentioned as "sectors of the future" in the strategic objective (ECOWAS 2022a), which aims to build the capacities of ECOWAS and its member states to implement policies and actions that combat climate change. In particular, these actions are to be achieved through education, gender mainstreaming, entrepreneurship, innovation, and support for research and technological development, all of which make use of economic opportunities and develop the blue and green economies.

The strategy recognizes that the region's economy is driven by resource-intensive models that contribute to the degradation of biodiversity and the environment, and are associated with low performance. This narrative must be shifted to more low-carbon models by mobilizing financial and technical solutions embodied in the ECOWAS member states' nationally determined contributions, which they committed to in order to meet the objectives of the Paris Climate Agreement, and thereby pave ways for more nature-based solutions, including bioeconomy models. The ECOWAS strategy specifically includes science, technology, innovation, and education—vital components of bioeconomy models.

Science and Technological Innovation

ECOWAS has always considered science and technological innovation to be indispensable in initiating the socioeconomic and cultural development and competitiveness of its member states. It expressed its commitment to this innovation through Article 27 of the Constitutive Treaty on Scientific and Technological Cooperation (ECOWAS 2022a). Furthermore, ECOWAS adopted a regional policy on science, technology, and innovation (ECOPOST; ECOWAS 2011), alongside an action plan for its implementation. In addition, the REC developed a directive on science, technology, and innovation and a regulation on the criteria for the selection of ECOWAS Centres of Excellence, adopted at the 41st Ordinary Summit of Heads of State and Government on June 29, 2012 (ECOWAS 2012). ECOPOST's ambition is to transform ECOWAS member states into emerging economies through the development and use of science, technology, and innovation in the socioeconomic and environmental sectors to achieve sustainable economic and social development, meet the present and future needs of their populations, and ensure a better quality of life.

Science, technology, and innovation (STI) are indispensable to the achievement of the SDGs. If a determined effort is made to build capacity in developing countries, STI can play a leading role in improving productivity and economic growth, promoting social inclusion, and fostering environmental sustainability.

The strategies developed for implementing ECOPOST to address environmental, climate change, and biodiversity challenges have focused significantly on building scientific capacity for the protection, conservation, and sustainable use of biological resources. They also emphasize providing scientific information to decision-makers for the preservation of biodiversity; strengthening the scientific capacity of decision-makers, scientific actors, organizations, and other stakeholders to contribute to climate change adaptation; supporting the adaptation of rural and urban populations—especially the most vulnerable—through participatory action research; and promoting the sharing of scientific and local knowledge on climate variability and change.

Southern African Development Community

Like ECOWAS, the Southern African Development Community (SADC) does not have a dedicated bioeconomy strategy, although two of its member states do (South Africa and Namibia). Notwithstanding this, the *SADC Vision 2050*, published in 2020, aims to transform the region into a competitive, middle- to high-income industrialized society (SADC 2020a). Among the nature-based economic models, the Vision explicitly features the green economy, calling it a fourth industrial revolution (or "Industry 4.0") with new opportunities and challenges for industrialization. It is believed that, if Industry 4.0 is democratized and the green economy takes hold, new industrialization pathways will open up or be triggered, including green economy clusters, bioeconomy clusters, and novel Industry 4.0 platforms (SADC, 2020). The Vision creates an enabling policy environment for bioeconomy development as one of the pathways to amplifying desirable futures. It calls for the development of additional policies at the regional and national levels to improve readiness for Industry 4.0, support sectors (especially mining) in shifting toward a circular economy, and support the development of strong service sectors (such as industries that use clean energy).

The green economy aims to catalyze the socioeconomic transformation of SADC toward a resource-efficient, environmentally sustainable, climate change–resilient, low-carbon development path and equitable society (SADC 2015). It will achieve this through the transition toward sustainable production, distribution, and consumption of goods and services. This results in improved human well-being and economic growth over the long term while mitigating the exposure of future generations to significant environmental risks and ecological scarcities, which is in line with international trends and sustainable development commitments. This way, the green economy is seen as an action-oriented approach to reach sustainable development that addresses the main challenges observed in recent years (such as unemployment and inequality, economic vulnerability to energy prices, desertification, deforestation, soil erosion, and loss of biodiversity) and turns them into opportunities (SADC 2015).

The objective of Vision 2050 is to facilitate the balanced and accelerated attainment of the agreed-upon goals, anchoring on the three pillars of sustainable development: environmental sustainability, economic well-being, and social equity (that is, promoting the alignment of operational planning across the SADC Secretariat and member states). It is expected to build on and catalyze these processes in the implementation of all SADC protocols, policies, and strategies, in particular the revised Regional Indicative Development Strategy, the recently approved Industrialization Strategy and Road Map, the Regional Infrastructure Development Master Plan, and the Regional Agriculture Policy.

As a result, the Regional Indicative Strategic Development Plan (RISDP) 2020–2030 (SADC 2020b) aims to find and use synergies across sectors, identify and avoid potential emerging bottlenecks and side effects, and fully harness green economy opportunities. The strategy provides information on the methodologies to be adopted to support customizing the approach at the country level, and identifies indicators to support each step of the policymaking process from a sectoral and integrated perspective at both the national and international levels.

The high-level strategic directives (or policy principles) of Vision 20250 identified indicate opportunities for SADC to foster the development of strategies, plans, and processes and to integrate mainstream green economy approaches into core development policies, strategies, and plans.

Green economy strategies and actions are proposed to achieve sustainable development. The strategies are underpinned by cross-sectoral linkages that may reach beyond national geographical boundaries and are based on the core goals of (1) improving energy and resource efficiency, (2) promoting low-carbon development, (3) supporting natural capital and ecosystem services, and (4) striving to improve equity and well-being.

Economic Community of Central African States Vision and Strategic Plan (2021–2025)

The Economic Community of Central African States (ECCAS) also does not have a dedicated bioeconomy strategy. ECCAS defined a clear vision to promote a common future in an environment of peace, security, and stability, ensured by sustainable development, good governance, the improvement of its citizens' living conditions, freedom, and justice. The priority areas of the Strategic Plan 2021–2025 (CEEAC 2021) include environmental integration and agriculture and rural development, which aim to preserve living conditions for future generations and ensure sustainable development by significantly and sustainably increasing the region's production, productivity, and competitiveness for food security and access to regional and international markets. Considering the importance of the Congo Basin Forest and the region's associated biodiversity and natural resource endowment, integrated nature-based solutions are pivotal. Specifically, the region is promoting environmental economics through accelerating the structuring and operationalization of the green economy and corporate social responsibility system, the green economy fund, traditional know-how using natural resources, and the craft economy and small enterprises using biological and nonbiological natural resources.

The Congo Basin, estimated at 227 million hectares, is home to the world's second-largest tropical rainforest, which acts as the "lungs" of Africa. The Congo Basin Forest Commission is committed to further promoting the green economy by adopting public strategies that foster sustainable natural resource management, following guidelines that integrate private sector companies and civil society organizations, promote sustainable agriculture and sustainable value-added chains, pursue the objective of net-zero deforestation in all sectors of production (wood, mining, agro-food, infrastructure), institutionalize independent certification for natural resource exploitation, ensure strict compliance with mandatory environmental and social impact studies in all investment projects, and strengthen the organization of local populations in forest areas (CEEAC 2021). These guidelines are aligned with and provide opportunities for the bioeconomy to improve the integration of science, technology, and innovation in the process of green growth through investment in sustainable infrastructure, better management of natural resources, resilience to natural disasters, and enhancement of food security.

Constraints to Implementing Climate Actions and Expanding Bioeconomy Uptake

Climate action in Africa advanced significantly with the convening of the inaugural Africa Climate Summit in 2023 in Kenya. This provided a convergence of ideas on climate action for African economies, and the resulting declaration acknowledged the impact of climate change on African economies, while also highlighting opportunities for increasing political collaboration and investments to unlock the potential of entrepreneurial opportunities across the continent in the utilization of renewable biological resources from the land and sea in the production of food, energy, and other goods and services (AUC 2023). Without making explicit reference to the bioeconomy, the African Leaders Nairobi Declaration on Climate Change and Call to Action highlights, in multiple sections, concern for the impact of climate shocks and stresses on multiple subsectors related to the use of renewable biological resources of the bioeconomy.

Examples of subsectors related to the bioeconomy mentioned in the Nairobi declaration include the following:

- Scaling up access to finance and technology adoption for the use of renewable energy across the continent
- Supporting agriculture and forestry, both as sources of economic livelihood and as carbon sinks to lock in GHG emissions contributing to climate change
- Promoting the regenerative blue economy and supporting implementation of the Moroni Declaration for Ocean and Climate Action in Africa and the Great Blue Wall Initiative, while recognizing the circumstances of Africa's Island States
- Increasing continental collaboration through trade, technology transfer, and other means to maximize the benefits of the bioeconomy

The impacts of climate change on the bioeconomy of African countries threaten to move more people toward multidimensional poverty (World Bank 2023) due to a lack of opportunities and resources for growing prosperity. However, the Nairobi declaration shares opportunities ripe for market-creating innovations: for example, by highlighting that "600 million people in Africa still lack access to electricity while about 970 million lack access to clean cooking, and 400 million people in Africa have no access to clean drinking water and 700 million [are] without good sanitation" (Christensen et al. 2019), the declaration demonstrates the potential for entrepreneurship to create value propositions for these needs to be met through affordable and accessible means.

The Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods mentions both the value of the bioeconomy to wider economic prosperity and its vulnerability to environmental shocks and stresses, including climate change (AUC 2014.) While certain aspirational targets were set to be achieved by 2025, the subsequent biennial review (AU 2018, 2020, 2022, 2023) of self-reported progress toward achieving these targets showed that most countries are still not on course to achieve them. Member states agreed to track the seven commitments against 46 indicators: in the 2017 review, 20 of the 47 reporting countries were on track to achieve all commitments, but this declined to 4 out of 49 countries in the 2019 review, and fell further to just 1 country in the 2021 review (AUC 2022). By the 2023 review, no country was deemed to be on track to achieve all the commitments and targets of the Malabo Declaration by 2025 (AUC 2018, 2020, 2022, 2024). The inability of governments to achieve these targets has a meaningful impact on the growth of the bioeconomy and its contribution to wider economic prosperity.

Analysis shows that 14 African countries are among the 20 most vulnerable to climate shocks and stresses globally (Chen et al. 2023). In this context, vulnerability measures a country's exposure, sensitivity, and ability to adapt to the negative impact of climate change. The literature has highlighted issues such as limited financial resources, weak institutional capacity, vulnerability to climate impacts, lack of technological infrastructure, and dependency on fossil fuels as barriers to making progress on climate action. For the bioeconomy, growth is stifled by issues such as limited research and development capacity, fragmented value chains, land use conflicts, technical capacity deficiencies, and limited public policy support (Aidoo et al. 2023).

In its report, the Malabo Montpellier Panel (2022b) noted that the enablers of a thriving bioeconomy in Africa include governance; demand for bioproducts; intellectual property; science, research, and innovation; infrastructure; finance; and partnerships and collaborations. It also explored the contextual use of public policy, highlighting four country cases (Ghana, Namibia, South Africa, and Uganda) where opportunities in the bioeconomy are being explored. In addition to these four countries, other African economies, including Kenya's and Nigeria's, are making progress toward anchoring the bioeconomy in their development plans.

Kenya's bioeconomy leads in export revenues, with tea, cut flowers, and coffee having the three highest revenues (Growth Lab 2024). Kenya also aims to achieve 100 percent renewable power by 2030 and to fuel the green industries of the future by 2040 (IRENA 2023). Although it does not have a national bioeconomy strategy, Kenya benefits from the EAC's bioeconomy strategy (EAC 2022), which aims to develop a low-carbon future for the region, link farmers to new value chains, and create incentives for the informal sector and productive partnerships (Ecuru 2020). Gatune and colleagues (2021) mapped out various scenarios for the growth of the bioeconomy in the East Africa region and suggested that to maximize the potential of the bioeconomy for shared prosperity, attention should be paid to "developing regional and national platforms to bring stakeholders together to ensure policy coherence, creating innovation platforms to drive R&D, developing outreach programs to communicate bioeconomy prospects, and stimulating demand for bioproducts through mandates (e.g., ban on single-use plastics), incentives (e.g., government procurement quotas)" (11) and removing disincentives (such as taxes, regulatory red tape, etc.) that influence bioeconomy interventions.

Nigeria's investments in the bioeconomy have not been explicit in national policy. However, evidence indicates that a focus on biotechnology and bioenergy is an emerging area of priority, in addition to existing subsectors of the bioeconomy. Nigeria's Biosafety Bill was signed into law in 2015—establishing the National Biosafety Management Agency (NBMA)—and amended in 2019 (Nigeria, National Assembly of the Federal Republic of Nigeria 2019). It provides the NBMA with the authority to establish "a regulatory framework, an institutional and administrative mechanism for safety measures in the application of modern biotechnology in Nigeria with the view to preventing any adverse effect on human health, animals, plants, and environment" (Nigeria, National Assembly of the Federal Republic of Nigeria 2019, i). Since its passing, Nigeria has joined leaders on the continent in commercializing biotechnology agriculture products, using the *bacillus thuringiensis* (Bt) bacteria, which produces proteins that are toxic to certain insects. The commercial release of Bt cotton, Bt cowpea, and Bt maize aims to increase food security, guarantee livelihoods for farmers, and improve resilience to shocks and stresses (especially in the case of the Bt TELA maize that is drought tolerant and also resistant to the fall armyworm). Kansiime, Rwomushana, and Mugambi (2023) estimate that economic losses due to the fall armyworm are valued at US$9.4 billion. Although the country has a national biofuels strategy—requiring 10 percent of fuels to be blended with ethanol, which can be sourced from crops—there currently do not appear to be compelling political or commercial incentives to implement it (Nwozor et al. 2021).

An appraisal by the Malabo Montpellier Panel in 2022a and Chapter 9 of this report of progress made in various countries toward expanding the benefits of the bioeconomy in the face of climate constraints reveals that various countries are at different stages of developing dedicated approaches for the bioeconomy.

Implications for Africa's Growth

As Africa embraces the bioeconomy, it is important to analyze the implications for the continent's future growth and development. Here we cluster these implications in three areas:

Policy

Concerning policy, governments should start to create incentives and remove disincentives for bioeconomy advancements. These incentives could be economic, such as providing tax relief for bio-based products, or environmental, such as enforcing bans on unsustainable practices, as is being done by the bans on single-use plastics in Kenya, Rwanda, Tanzania, and Uganda. Such bans can provide incentives for industry and academia to develop biodegradable alternatives. Additionally, regulatory standards and their enforcement is critical to ensure investors' confidence. Standards for most bio-based products are lacking in many countries. For example, until recently, there were no standards on the use of insect proteins as ingredients in animal feed. Uganda and Kenya championed the development of these standards, which is leading to the growth of the BSF enterprise in the region. The current efforts by stakeholders in the insect protein value chain to have continent-wide standardization are commendable, and the same standards should apply to other emerging bio-based products. Most of all, policy incentives and associated standardization will ensure that bioeconomy industries, products, and services can compete favorably in domestic, regional, continental, and international markets. Therefore, a clear theory of change, impact pathways, and indicators must be developed as part of the policy design process.

Financing

With respect to financing, governments need to design financing mechanisms that support the growth of bioeconomy enterprises. These financing mechanisms may be extended from traditional ones such as climate funds, biodiversity funds, or industrial development funds. It may be worthwhile to establish quotas within such funds to support dedicated bioeconomy projects. This is necessary given that bio-based innovations are inherently risky and take much longer to mature and reach the market. Even when they are in the market, their profitability may be low at first. Larger-scale investors or companies should see opportunities to grow their businesses using bio-based innovations. Such investors can be attracted when the right policies are in place, such as enabling regulatory standards for bio-based goods and services. Public financing should also be considered to support research and innovation in universities and research institutes to provide the pipeline for knowledge and skills for the bioeconomy. Therefore, deliberate measures should be taken to support financial mechanisms at national and regional levels to promote bio-based products and services. Academics and policymakers are encouraged to monitor the development of their bioeconomies, including budgeting for and monitoring financial flows into bioeconomy projects.

Skills

Bioeconomy enterprises are inherently knowledge intensive. Therefore, university scientists ought to be champions in linking their knowledge with industry. Good capacity-strengthening programs will be needed to build the right type of skill sets for the future economy, which will be the bioeconomy. The Second Ten Year Implementation Plan for the AU Agenda 2063 provides meaningful milestones for increasing skills in higher education (postgraduate training) as well as technical and vocational education and training (AUC 2024b). These plans should give specific consideration to skills necessary for the future of work and industries that result from advancing the bioeconomy in the continent.

Conclusion

The bioeconomy is now widely regarded as a pathway for future growth and development, considering the need to lower or reverse global warming, preserve biodiversity, and, at the same time, ensure that people have decent jobs and livelihoods. Africa, which has significantly lower carbon emissions than other regions, has a competitive advantage in developing a sustainable bioeconomy. The EAC has set a good example by developing a dedicated, regional bioeconomy strategy; other regional economic blocks should do the same. Ultimately, when the bioeconomy strategies of the regions are put together, they would reflect a true African bioeconomy. The continent should harness opportunities for collaboration and partnerships globally in the advancement of its bioeconomy, while considering its unique needs, values, and competitive advantages.

In advancing its bioeconomy, Africa should always uphold the cross-sectoral nature of the bioeconomy, noting that digitalization will be a key enabler as much as the environment and industry. Ultimately, Africa's bioeconomy will be anchored in its agriculture and food systems, given that this sector contributes more than 30 percent of the continent's GDP. Therefore, every effort should be made to link food systems to every sector of the economy, and this chapter provides evidence that the bioeconomy is best suited to achieve that end.

FEATURED ISSUE 2

The Rise of Environmental Impact Reporting in Agrifood Systems

Koen Deconinck

A new trend is emerging as food supply chains move toward greater reporting of quantified environmental impacts, such as carbon footprints. The last few years have witnessed rapid developments, with a large number of both public and private initiatives underway. This "fast and furious" trend (Deconinck, Jansen, and Barisone 2023) could provide better information to help reduce environmental pressures in the agrifood sector. At the same time, different methodologies and reporting requirements could lead to a fragmented landscape, and there is also a risk that small producers, especially in the Global South, will be disproportionately affected, as they are least likely to be able to provide the necessary reporting data.

The European Union's Corporate Sustainability Reporting Directive (CSRD), which went into effect in January 2023, is one example of this new reporting trend. The CSRD requires all large firms, and all firms on the stock market in the European Union, to report on a range of sustainability indicators (EU 2022). So-called "Scope 3" greenhouse gas emissions are one required indicator: while Scope 1 emissions encompass those from a firm's own activities and Scope 2 emissions result from a firm's purchased energy, Scope 3 emissions cover emissions from the firm's "upstream" and "downstream" activities, such as emissions embedded in purchased goods and services. For example, if the production of cocoa for a chocolate bar sold in a supermarket in France or Spain involved deforestation, the emissions resulting from land use change would be part of the Scope 3 emissions for the supermarket, the candy manufacturer, and the commodity traders. The European Union's rules do not require firms to specify the Scope 3 emissions for every product in detail, but it is clear that firms will begin to pay greater attention to the upstream emissions of products they purchase and will likely ask for additional information from their suppliers (OECD and WEF 2023).

In addition to the example of the CSRD, many firms are voluntarily reporting their emissions through the CDP platform, a global disclosure system for various actors, including investors and companies, to manage their environmental impacts (CDP 2024a). In 2023, more than 23,000 firms worldwide engaged in this voluntary reporting, an increase of 24 percent compared with the previous year (CDP 2024b). Many firms are also setting voluntary targets, including for their Scope 3 emissions, through the Science-Based Targets initiative, which provides companies with a path to reduce emissions in line with the Paris Agreement on climate change (Science-Based Targets 2024a). Last year, the number of firms with validated targets doubled to 4,200 (Science-Based Targets 2024b), a figure that includes most of the world's leading retailers.

The rise in environmental impact reporting is underpinned by growing demand from consumers and civil society actors, as well as investors. Consumers are increasingly interested in knowing the environmental impact of their food products, including climate impacts. In response, many labeling schemes have been created to communicate quantified environmental impacts across several dimensions, such as water, climate, and biodiversity. These new schemes differ from traditional sustainability labels (such as organic and Fairtrade, among others), as they are based on a quantification of environmental impacts.

Several developments are also making it easier to quantify and communicate impacts. These include the development of clear reporting standards (such as the ISO standards on life-cycle assessment [ISO 2006a; ISO 2006b] or the Greenhouse Gas Protocol standards on emissions reporting [WBCSD and WRI 2004]), the availability of farm-level tools to calculate impacts, and the emergence of platforms to enable sharing these data between supply chain actors. Another overarching trend is the growing use of a "supply chain lens" to address global environmental issues and resulting improvements in supply chain traceability.

Greater environmental impact reporting could provide powerful information to help reduce the environmental footprint of global agrifood systems. It is useful to distinguish three levers that can be unlocked with better data:

- **A shift from food products with higher average environmental impacts to those with lower average impacts.** For example, the available evidence shows that products such as beef, lamb, or cheese have higher average emissions than those such as poultry or pork. In turn, poultry and pork have higher emissions than plant-based products.

- **A shift within each product category from producers with higher emissions to those with lower emissions.** The available evidence shows enormous heterogeneity around the average, meaning that traders, manufacturers, and retailers—as well as consumers—might increasingly shift toward suppliers who can demonstrate lower environmental impacts.
- **The adoption of techniques and practices that lower emissions.** Farmers and other supply chain actors can generally take action to reduce their environmental impacts. Detailed calculation tools could help them identify the best approach and demonstrate this to buyers.

However, the same trend of environmental impact reporting also poses important risks: for example, it is possible that instead of converging, different initiatives and requirements will instead create a fragmented landscape, leading to confusion and high transaction costs. Even if this hurdle can be overcome, another risk is that the trend will disproportionately affect producers in low- and middle-income countries. On average, these producers often have higher emissions intensities, and they may have more difficulty in demonstrating their environmental footprint. Much of the current science on measuring environmental impacts was developed in high-income countries, while detailed field studies to calibrate quantification tools are scarcer in low- and middle-income countries.

The trend could have far-reaching consequences for African agrifood exports if, for example, firms in high-income markets start asking African suppliers for quantified environmental impacts. It is unclear whether producers with lower environmental impacts would be able to reap a price premium, or whether producers with a worse footprint would be excluded from supply chains. Other open questions include the extent to which downstream supply chain actors would be involved in helping to reduce emissions from their supplier base or to which global trade flows might be reoriented in response to this new trend in impact reporting.

CHAPTER 13

Tracking Key CAADP Indicators and Implementation Processes[1]

Wondwosen Tefera, Paul Maina Guthiga, Julia Collins, and Tsitsi Makombe

1 The authors gratefully acknowledge Marvin Mulima for research assistance.

Introduction

Recognizing the central role that agriculture plays in development, in 2003, the African heads of state and government launched the Comprehensive Africa Agriculture Development Programme (CAADP) as a continentwide framework for accelerating broad-based economic growth and progress toward poverty reduction and food and nutrition security. In 2014, African leaders expanded the CAADP agenda by adopting the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods, outlining seven key commitments for accelerated agricultural growth and transformation. Through the declaration, they pledged to increase investment in agriculture, end hunger and halve poverty by 2025, boost intra-African agricultural trade, enhance resilience to climate variability, and strengthen mutual accountability for actions and results by conducting a continental Biennial Review (BR) of progress made toward achieving the commitments (AUC 2014). They also recommitted to uphold the CAADP principles and values of evidence-based planning, policy efficiency, dialogue, review, accountability, and exploiting regional complementarities as well as to achieve the CAADP targets of 6 percent annual agricultural growth and allocation of at least 10 percent of national budgets to agriculture.

After two decades of implementation, CAADP has undoubtedly raised the profile of African agriculture, mobilized political support for and investments in the agriculture sector, and fostered broad-based participation of both state and nonstate actors in agriculture policy discourse especially through its promotion of mutual accountability (Benin et al. 2018; Ulimwengu et al. 2020). As a result, Africa has seen notable progress in achieving higher economic and agricultural growth, boosting agricultural productivity, reducing hunger and poverty, and expanding agricultural trade (Badiane, Collins, and Ulimwengu 2020). Nevertheless, Africa's performance was stronger during CAADP's first decade (2003–2013) than during its second decade, under the Malabo Declaration (2014–2022), when the continent's performance has been uneven due to a plethora of factors including a global economic slowdown in 2016, the COVID-19 pandemic, effects of the Russia–Ukraine war, the impacts of climate change and pest outbreaks, and growing political conflicts (Collins et al. 2022; Collins, Tefera, and Wambo Yamdjeu 2023).

Therefore, to accelerate agrifood system transformation on the continent and with the Malabo Declaration set to expire at the end of 2024, the African Union Commission (AUC) has been leading an effort to develop a robust, evidence-based post-Malabo CAADP agenda. The effort has included inviting submissions of independent memoranda on key priorities for a post-Malabo agenda from different CAADP stakeholder groups and undertaking broad and inclusive stakeholder regional consultations and analytics to guide the creation of an agenda that will inform a new CAADP Declaration and Action Plan, expected to be adopted by the African heads of state and government in Kampala, Uganda, in January 2025. AKADEMIYA2063 has played a key role in supporting AUC with the agenda development process, including mobilizing technical expertise and content (led by African centers of excellence and supported by global knowledge centers) to guide the development of an evidence-based post-Malabo agenda. More specifically, AKADEMIYA2063 mobilized knowledge centers that convened and led the work of 13 technical working groups (TWGs) in developing thematic technical content for the agenda. AKADEMIYA2063 also assembled a technical review committee made up of eminent African and international development experts to assess the technical rigor of the thematic content developed by the TWGs.

The Regional Strategic Analysis and Knowledge Support System (ReSAKSS), was established in 2006 to provide policy-relevant analysis, data, and tools to support the formulation and implementation of evidence-based agriculture-sector policies and strategies, as well as to enable CAADP policy dialogue, peer review, benchmarking, and mutual learning processes. AKADEMIYA2063 leads the work of ReSAKSS in partnership with AUC, the African Union Development Agency–NEPAD (AUDA-NEPAD), and leading regional economic communities (RECs). Since 2008, ReSAKSS has tracked CAADP implementation progress, initially using the first CAADP monitoring and evaluation (M&E) framework (see Benin, Johnson, and Omilola 2010) and then using the CAADP Results Framework (RF) for 2015–2025 (see AUC and NPCA 2015) developed in 2015 to track CAADP progress under the Malabo Declaration.

The CAADP RF is organized on three levels: level 1—outcomes; level 2—outputs; and level 3—inputs:

- Level 1 of the CAADP RF includes relatively broad development outcomes and impacts to which agriculture contributes, including wealth creation;

food and nutrition security; enhanced economic opportunities, poverty alleviation, and shared prosperity; and resilience and sustainability.

- Level 2 includes the outputs from interventions intended to transform the agriculture sector and achieve inclusive growth: improved agricultural production and productivity; increased intra-African trade and functional markets; expanded local agro-industry and value chain development that is inclusive of women and youth; increased resilience of livelihoods and improved management of risks in agriculture; and improved management of natural resources for sustainable agriculture.
- Level 3 includes inputs and processes required to strengthen systemic capacity to deliver CAADP results and create an enabling environment in which agricultural transformation can take place: effective and inclusive policy processes; effective and accountable institutions that regularly assess the quality of implementation of policies and commitments; strengthened capacity for evidence-based planning, implementation, and review; improved multisectoral coordination, partnerships, and mutual accountability in sectors related to agriculture; increased public and private investments in agriculture; and increased capacity to generate, analyze, and use data, information, knowledge, and innovations.

The CAADP RF comprises 38 indicators: 14 for level 1, 12 for level 2, and 12 for level 3 (Table 13.1). ReSAKSS tracks progress on CAADP indicators in the CAADP RF for 2015–2025 through its flagship Annual Trends and Outlook Report (ATOR) and website (www.resakss.org).

Whereas the CAADP RF is designed to help track progress in implementing the Malabo Declaration, the CAADP BR process initiated in 2015 introduced additional indicators specifically aimed at monitoring all seven of the Malabo commitments using the Africa Agriculture Transformation Scorecard (AATS). Twenty-four CAADP BR indicators were drawn from the CAADP RF and new indicators were added during four BR cycles, resulting in a total of 59 BR indicators compared with 38 RF indicators (Table 13.1).

The BR is the paramount continentwide mutual accountability process in the agriculture sector, allowing AU Member States to collectively review progress toward the Malabo goals and commitments. However, the CAADP RF is an important complement to the BR process as its indicators provide context for BR results and its coverage enables a range of analyses across the continent and over time. This chapter reviews progress on CAADP indicators using the CAADP RF because the RF data assembled by ReSAKSS are consistently available for a larger number of countries and for longer time periods than the BR data, including both pre- and post-CAADP eras (1995–2003 and 2003–2021). This in turn allows for aggregation across countries and an examination of trends over time periods and across different country groupings (for example, organized by economic categories, regional economic communities, and stage of CAADP implementation) that are not considered by the BR. Although the CAADP BR indicators are broader in coverage, there is considerable overlap between those indicators and those in the CAADP RF. Currently, ReSAKSS

TABLE 13.1—NUMBER OF INDICATORS IN THE CAADP RESULTS FRAMEWORK AND BIENNIAL REVIEW

CAADP Results Framework	Number of indicators
Level 1: Agriculture's contribution to economic growth and inclusive development	14
Level 2: Agricultural transformation and inclusive growth	12
Level 3: Systemic capacity to deliver results	12
Total number of indicators	**38**
CAADP Biennial Review and Africa Agriculture Transformation Scorecard	**Number of indicators**
Commitment 1: CAADP processes and values	3
Commitment 2: Investment finance in agriculture	6
Commitment 3: Ending hunger by 2025	26
Commitment4: Halving poverty by 2025	8
Commitment 5: Boosting intra-African trade in agricultural commodities and services	7
Commitment 6: Enhancing resilience to climate variability	4
Commitment 7: Mutual accountability for results and actions	5
Total number of indicators	**59**

Source: Authors based on AUC and NPCA (2015) and AUC (2014).

tracks progress on 18 CAADP BR indicators that overlap with the CAADP RF indicators it tracks (Table 13.2).

Six other CAADP RF and BR indicators overlap. However, these indicators are not yet included in the ReSAKSS database because the data are not available at all or are not available across all countries to allow for cross-country aggregation. They include indicators on postharvest loss, women's and children's dietary adequacy, resilience, sustainable land management, and capacity of statistical systems. Additional data gaps in other areas covered in the CAADP RF, including those on social protection and private sector investment, mean that currently only 27 of the 38 CAADP RF indicators can be tracked (Table 13.2). Although discussions on filling data gaps are underway among CAADP technical partners, increasing the availability of data in these areas can be challenging and will require resolute efforts by countries and their partners to develop and fund comprehensive data collection activities.

Objectives of the Chapter

In this chapter we review Africa's progress in CAADP process implementation and on the CAADP RF indicators to highlight areas of strong performance that need to be sustained or accelerated as well as areas of weak performance that require urgent attention to enable the continent to meet its Malabo Declaration agricultural transformation goals. The chapter examines progress on 27 of the 38 CAADP RF indicators for which cross-country data are available (Table 13.2). Details of the indicators and aggregate statistics are available in the data tables in Annexes 1–3 of this report. Progress on the RF indicators is discussed across different aggregated geographic and economic groupings of African countries by comparing trends in the RF indicators during the first five years after the adoption of CAADP (2003–2008) with later subperiods (2008–2014 and 2014–2023), with a particular focus on the Malabo Declaration period of 2014–2023.

TABLE 13.2—CAADP RESULTS FRAMEWORK INDICATORS DISCUSSED

Level 1: Agriculture's Contribution to Economic Growth and Inclusive Development
1. L1.1.1 GDP per capita (constant 2015 US$)
2. L1.1.2 Household final consumption expenditure per capita (constant 2015 US$)
3. L1.2.1 Prevalence of undernourishment (% of population)
4. L1.2.2a Prevalence of underweight, weight for age (% of children under 5)
5. L1.2.2b Prevalence of stunting, height for age (% of children under 5)
6. L1.2.2c Prevalence of wasting, weight for height (% of children under 5)
7. L1.2.3 Cereal import dependency index
8. L1.3.1 Employment rate
9. L1.3.3 Poverty gap at $1.90 a day (2017 PPP)
10. L1.3.4 Extreme poverty headcount ratio at $1.90 a day (2017 PPP), % of population
Level 2: Agricultural Transformation and Sustained Inclusive Agricultural Growth
11. L2.1.1 Agriculture value added (million, constant 2015 US$)
12. L2.1.2 Agriculture Production Index (2004–2006 = 100)
13. L2.1.3 Agriculture value added per agricultural worker (constant 2015 US$)
14. L2.1.4 Agriculture value added per hectare of agricultural land (constant 2015 US$)
15. L2.1.5 Yield for the five most important agricultural commodities
16. L2.2.1 Value of intra-African agricultural trade (constant 2015 US$, million)
17. L2.4.2 Existence of food reserves, local purchases for relief programs, early warning systems, and school feeding programs
Level 3: Strengthening Systemic Capacity to Deliver Results
18. L3.1.1 Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process
19. L3.2.1 Existence of inclusive institutionalized mechanisms for mutual accountability and peer review
20. L3.3.1 Existence of and quality in the implementation of evidence-informed policies and corresponding human resources
21. L3.4.1 Existence of a functional multisectoral and multistakeholder coordination body
22. L3.4.2 Cumulative number of agriculture-related public–private partnerships that are successfully undertaken
23. L3.4.3 Cumulative value of investments in the public–private partnerships
24. L3.5.1 Government agriculture expenditure (billion, constant 2015 US$)
25. L3.5.2 Government agriculture expenditure (% of total government expenditure)
26. L3.5.3 Government agriculture expenditure (% of agriculture value added)
27. L3.6.2 Existence of an operational country SAKSS

Source: AUC and NPCA (2015).

Note: GDP = gross domestic product; NAIP = national agriculture investment plan; NAFSIP = national agriculture and food security investment plan; PPP = purchasing power parity; SAKSS = Strategic Analysis and Knowledge Support System. Highlighted indicators are also Biennial Review indicators.

We first discuss CAADP implementation at the country and regional levels in terms of progress in developing evidence-based, Malabo-compliant national agriculture investment plans (NAIPs) and operationalizing CAADP mutual accountability processes to support agriculture sector review and dialogue through agriculture joint sector reviews (JSRs) and the CAADP BR. The CAADP implementation process is led by AUC and AUDA-NEPAD working in collaboration with national governments, RECs, nonstate actors, and development and technical partners. We discuss general progress in the implementation process while highlighting the contribution of ReSAKSS as a technical partner.

Progress in CAADP Implementation Processes

Implementation Support

CAADP implementation is largely realized at the country and regional levels through four main phases: (1) domestication of the Malabo Declaration; (2) development of a Malabo-compliant NAIP and regional agriculture investment plan (RAIP); (3) implementation of the NAIP and RAIP; and (4) assessment of NAIP and RAIP implementation progress through, respectively, a national agriculture JSR and a regional agriculture JSR. At the country level, domestication of the Malabo Declaration begins with an event led by AUC, AUDA-NEPAD, and RECs that convenes national CAADP constituencies to discuss and agree on a country roadmap to review and revise the NAIP. The roadmap specifies roles, timelines, and coordination modalities needed to generate a NAIP that receives broad support from national stakeholders. To date, domestication events have been held in 25 countries (Table L3(a) in Annex 3d).

Following the domestication event, countries update their existing NAIP or develop a new NAIP that is expected to go through an AUC-led independent technical review to assess whether it is Malabo compliant, that is, aligned with Malabo goals and targets. A total of 45 African countries have drafted, reviewed, and/or validated a Malabo-compliant NAIP (Table L3(a)). Only three RECs have developed first-generation RAIPs. However, not all of the NAIPs were developed through an AU-sponsored Malabo domestication process or were subject to an AU-led independent technical review to assess their compliance with the Malabo Declaration (Collins et al. 2022). A 2022 consultative dialogue held by AUC and AUDA-NEPAD identified several key constraints to NAIP and RAIP implementation, including technical capacity constraints in policy planning and implementation, economic and policy analysis, and M&E as well as insufficient multisectoral coordination and lack of policy coherence (AUDA-NEPAD 2022). Notably, the post-Malabo CAADP agenda included a TWG that focused on assessing CAADP implementation and coordination capacity issues. Recommendations of the TWG are expected to guide how to strengthen the implementation of NAIPs and RAIPs under a new 10-year CAADP agenda.

Mutual accountability is a core principle of CAADP that is operationalized through agriculture JSRs and the CAADP BR. JSRs provide an inclusive, evidence-based platform for multiple stakeholders to jointly review progress; hold each other accountable for actions, results, and commitments; and based on gaps identified, agree on future implementation actions. At the request of AUC and AUDA-NEPAD, ReSAKSS has been strengthening agriculture JSRs since 2014. ReSAKSS has, to date, conducted agriculture JSR assessments in 23 countries (Table L3(a)). In addition, at the regional level, ReSAKSS conducted JSR assessments for the Economic Community of West African States (ECOWAS) in 2015 and for the East African Community (EAC) in 2019. The assessments evaluate the institutional and policy landscape as well as the quality of current agricultural review processes, identifying areas that need strengthening in order to help countries and RECs develop JSR processes that are regular, comprehensive, and inclusive. ReSAKSS and its partners have used outcomes of the assessments to strengthen agriculture JSR processes where they exist (for example, in Ghana and Malawi) and establish new JSRs (for instance, in Senegal and Burkina Faso).

Following the JSR assessments and the implementation of JSR best practices and action plans to improve the quality of the agriculture JSRs, several major improvements have ensued. They include the improvement of accountability standards and the strengthening of multistakeholder engagement. We also observe an increase in the active inclusion and participation of nonstate actors, such as farmer-based organizations and civil society organizations, in JSR national meetings (Ulimwengu et al. 2020). Finally, the JSRs have sparked multistakeholder discussions on the need to direct public projects and resources away from areas with a significant presence of nongovernmental organizations performing similar tasks and thus avoid unnecessary duplication of efforts (Matchaya et al. 2022).

Biennial Review

In the Malabo Declaration, the AU Member States agreed to report, on a biennial basis, their progress in achieving the declaration's seven commitments. Seven thematic areas of performance have been translated from the seven commitments to evaluate country performances. In 2018, 2020, 2022, and 2024, AUC released, respectively, the inaugural, the second, the third, and the fourth BR reports and the corresponding AATSs in order to assess performance in implementing the Malabo Declaration.

During the inaugural BR, for the seven thematic areas of performance, 23 performance categories and 43 performance indicators were defined for monitoring and reporting on the Malabo Declaration goals and targets. The number of performance categories increased to 24 and that of performance indicators to 47 at the time of the second (2020) and the third (2022) BR reportings. In the fourth (2024) BR reporting, the number of performance categories increased further to 29 while 12 more indicators were added, bringing the number of performance indicators to 59.

The CAADP BR process promotes mutual accountability by reviewing country performance in progressing toward meeting the Malabo Declaration commitments by 2025. Along with other technical partners, ReSAKSS supports the BR process by helping to improve the BR technical guidelines and tools, including introducing the digital BR (eBR) data entry platform and the BR country reporting profile; training country and regional BR teams on the guidelines and tools; and supporting countries and RECs with data analysis, reporting, cleaning, and validation. For the fourth BR, 49 out of 55 AU Member States submitted country BR reports, compared with 51, 49, and 47 during the third, second, and inaugural BRs, respectively (Table L3(a)).

Africa's performance over the four BR cycles shows that the continent has been consistently off track for meeting the Malabo goals and targets by 2025. In the inaugural BR, the overall score for Africa was 3.6 out of 10, which increased to 4.03 during the second BR. But Africa was below the minimum scores to be on track, which were 3.94 and 6.66, respectively, in the first and second BRs. In the third and fourth BRs, Africa scored 4.32 and 4.56, respectively. Both scores, however, fell far below the benchmark (minimum) scores of 7.28 during the third BR and 9.29 in the fourth BR cycle. Although the scores were insufficient for achieving the Malabo goals and targets, it is important to note that the continent improved its scores during each BR cycle.

With regard to each of the commitments, the results show that Africa was on track in four of the seven commitments during the inaugural BR (Table 13.3). In the following three BRs, the continent veered off track in all the commitments. Nonetheless, we note consistent improvement in scores over the whole BR period for commitments 3, 6, and 7, and successive improvements in scores for commitment 4 except for the second BR. On the other hand, Africa's score on commitment 2 consistently worsened throughout the first three BR periods, and did not improve in the fourth. The same was true for commitment 5 beginning with the third BR. Despite being off track, Africa registered improvements in overall scores from the inaugural BR to the fourth BR. Those improvements were not realized in all themes, as other themes were characterized by worsening scores.

Performance among the different country classifications shows that some of the subgroupings were on track during the inaugural BR. Those include eastern Africa, southern Africa, countries with less favorable agriculture conditions and more favorable conditions, and upper-middle-income countries. All of these subgroups were able to surpass the benchmark score of 3.94 out of 10 and, hence, were on track as of the inaugural BR to meet the Malabo goals and targets in 2025. But, beginning with the second BR, none of the different subgroups has

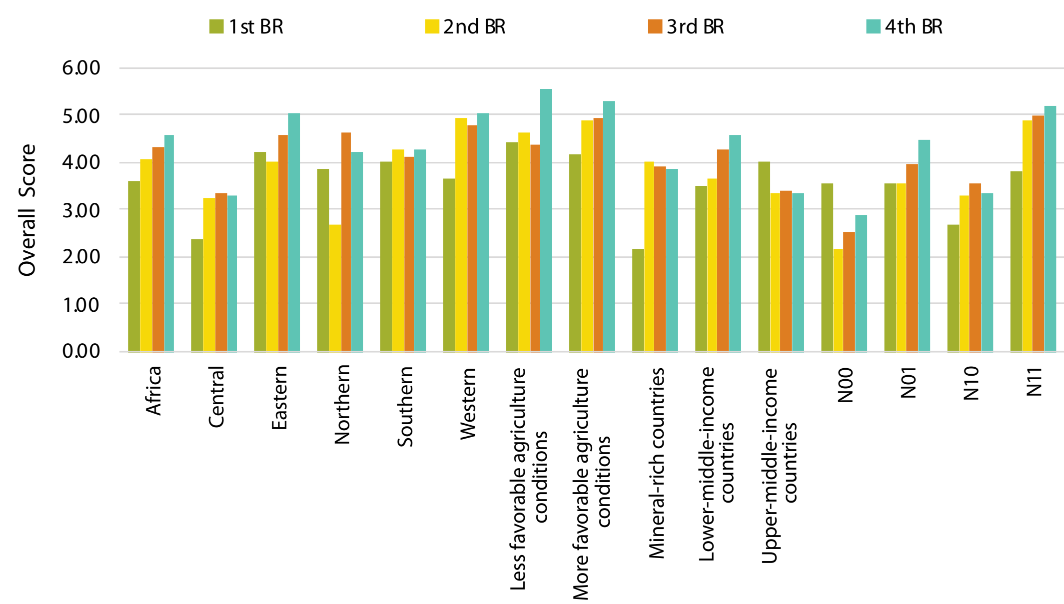
TABLE 13.3—BR SCORES BY COMMITMENT AND BR CYCLE

BR Commitments	1st BR (2018)	2nd BR (2020)	3rd BR (2022)	4th BR (2024)
Commitment 1: CAADP processes and values	5.53	7.29	7.28	7.66
Commitment 2: Investment finance in agriculture	3.54	3.46	3.15	3.15
Commitment 3: Ending hunger by 2025	1.82	2.2	2.71	2.9
Commitment 4: Halving poverty by 2025	2.67	1.81	2.69	3.04
Commitment 5: Boosting intra-African trade in agricultural commodities and services	2.45	2.87	2.44	2.23
Commitment 6: Enhancing resilience to climate variability	3.86	4.59	5.71	5.91
Commitment 7: Mutual accountability for results and actions	5.35	5.98	6.26	7.02

Source: AUC (2018, 2020, 2022, 2024).
Note: Green shading represents being on track; red shading means being off track. BR = Biennial Review.

been on track. In addition to Africa as a whole, however, we note consistent improvements in BR scores over the successive BRs among the countries with more favorable agriculture conditions, among lower-middle-income countries, and among the countries that formulated either the second generation of a NAIP (N01) or both a first and second generation NAIP (N11) (Figure 13.1). At the country level, the number of countries that were on track declined from 20 in the first BR to four in the second BR and down to one in the third BR. With a high benchmark score to assess progress in the fourth BR (9.29 out of 10), no country is on track to achieve the Malabo commitments by 2025. However, a number of countries improved their scores during each BR cycle despite not being on track . The fourth BR report shows that 20 out of 49 reporting AU Member States, although not on track, are progressing well toward achieving the Malabo commitments, compared with 15 during the third BR and nine during the second BR (AUC 2024).[2]

FIGURE 13.1—BR SCORES FOR IMPLEMENTING MALABO DECLARATION



Source: Authors' illustration based on AUC (2018, 2020, 2022, and 2024).

Note: The N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

Assessments of data quality and the rate of data reporting over the four BR cycles show that Africa needs to do more and better to address those issues. After four rounds of the BR, findings show that data quality, missing values, and other issues continued to be prevalent, although the extent of the problem markedly differs among the reporting countries (see AUC [2024] for a thorough assessment of data quality issues for the fourth BR).

Following the publication of each BR report, ReSAKSS takes part in a critical analysis organized by AUC and AUDA-NEPAD with the objective of learning from the process and improving the quality of data and reporting for the next BR cycle. Such analysis consists of technical review of the indicators, technical guidelines, data collection, data sources, challenges with reporting on the indicators, and so forth. The analyses help to identify challenges with regard to reporting on the indicators and possible remedial measures that need to be taken to address such challenges. The critical analysis of the fourth BR cycle will help improve the fifth BR process, which is the last BR cycle under Malabo.

Moreover, ReSAKSS has prepared several country and regional briefs that distill findings of the BR for country and regional learning events. The briefs show that the BR process has led to an increased agriculture sector investment in Côte d'Ivoire, Ghana, and Niger; the incorporation of BR indicators into national agricultural surveys in Mozambique and Togo; and more inclusive policy dialogues in Malawi and Mozambique (Matchaya et al. 2022). Such findings underscore the value of the CAADP BR process and trigger policy and programmatic adjustments in pursuit of desired Malabo goals and targets.

Progress on CAADP Indicators

In this section, we examine Africa's performance on 27 of the 38 CAADP RF indicators for which data are available, organized by the three RF levels. Detailed

2 Progressing well means making relatively good progress toward the benchmark score—for example, in the fourth BR, progressing well meant a country achieved a score of 5 or greater out of 10 but less than the benchmark of 9.29.

data on the 27 indicators are presented in Annexes 1 to 3. The annexes include data on the quantitative indicators at the aggregate level for seven different groupings:

- Africa as a whole
- The AU's five geographic regions—central, eastern, northern, southern, and western
- Five economic categories—low-income countries with less favorable agricultural conditions, low-income countries with more favorable agricultural conditions, mineral-rich low-income countries, lower-middle-income countries, and upper-middle-income countries[3]
- Eight RECs—Community of Sahel-Saharan States (CEN-SAD), Common Market for Eastern and Southern Africa (COMESA), EAC, Economic Community of Central African States (ECCAS), ECOWAS, Intergovernmental Authority on Development (IGAD), Southern African Development Community (SADC), and Arab Maghreb Union (UMA)
- By the period during which the country signed the CAADP compact—CC0, CC1, CC2, and CC3[4]
- By the level or stage of CAADP implementation reached by the country by the end of 2015—CL0, CL1, CL2, CL3, and CL4[5]
- By whether the country has formulated a first- or second-generation NAIP—N00, N10, N01, and N11[6]

Annex 4 lists countries in the various geographic, economic, and REC categories; Annex 5 lists the countries in the different groupings for CAADP compact signing or level of implementation reached; and Annex 6 lists countries by NAIP formulation category. Complete information for all categories is provided in Annexes 1 to 3. The discussion here focuses on progress among different geographic groupings, economic categories, RECs, and NAIP categories. Progress is reported over different subperiods, with achievement in the early CAADP subperiod of 2003–2008 compared with achievements in the later subperiods of 2008–2014 and 2014–2023.[7] The discussion in the chapter focuses mainly on progress during the Malabo Declaration period to date, that is, from 2014 to the last year with available data. For all indicators, changes over periods are reported in terms of annual average percentage change.

The discussion of trends and changes in CAADP indicators pertains to country categories or groupings as a whole and not to individual countries within the categories—for example, the measures reported relate, for example, to Africa as a whole, central Africa as a group, ECOWAS members as a group, and groups of countries categorized by their stage of NAIP formulation experience. Presenting the trends by different groups helps to determine how the implications for strengthening or maintaining desirable outcomes or for

3 The five economic categories are exclusive, with countries first classified as low-income, lower-middle-income, and higher-middle-income. Low-income countries are then classified as having more or less favorable agricultural conditions. Then, countries with more favorable agricultural conditions are classified as mineral-rich or not. See Benin, Johnson, and Omilola (2010) for a description of the categorization methodology and the criteria used for classifying countries based on income, favorability of agricultural conditions, and mineral wealth.

4 CC0 = group of countries that have not signed a CAADP compact; CC1 = group of countries that signed the compact in the period 2007 to 2009; CC2 = group of countries that signed the compact between 2010 and 2012; CC3 = group of countries that signed the compact between 2013 and 2015.

5 CL0 = group of countries that have not stared the CAADP process or have not yet signed a compact; CL1 = group of countries that have signed a CAADP compact; CL2 = group of countries that have signed a compact and formulated a NAIP; CL3 = group of countries that have signed a compact, formulated a NAIP, and secured one external funding source; CL4 = group of countries that have signed a compact, formulated a NAIP, and secured more than one external funding source. Obtaining funding for NAIPs is an important step in CAADP implementation, as countries that have secured external funding are expected to be better able to implement NAIPs and other agricultural investments (Benin 2016).

6 N00 = group of countries that have neither a first-generation NAIP (NAIP1.0) nor a second-generation NAIP (NAIP2.0); N10 = group of countries that have NAIP1.0 but do not have NAIP2.0; N01 = group of countries that have NAIP2.0 but not NAIP1.0; N11 = group of countries that have both NAIP1.0 and NAIP2.0. A second-generation NAIP refers to a NAIP that takes into account the commitments of the 2014 Malabo Declaration. Thus, a NAIP for a country can be considered second generation even if the country does not have a pre–Malabo Declaration, first-generation NAIP. Such countries are in country category N01.

7 Considering that CAADP was launched in 2003, renewed in 2008, and renewed again in 2014 with the Malabo Declaration, the years 2003, 2008, and 2014 represent important CAADP milestones. Therefore, the post-CAADP subperiods for reporting on progress use overlapping years to reflect that these milestones usually occurred in June in the middle of the year—that is, 2003 to 2008, 2008 to 2014, and 2014 to 2023.

reversing undesirable outcomes under the CAADP process may differ across the continent, without inference of causality.

CAADP Results Framework Outcome (Level 1) Indicators: Agriculture's Contribution to Economic Growth and Inclusive Development

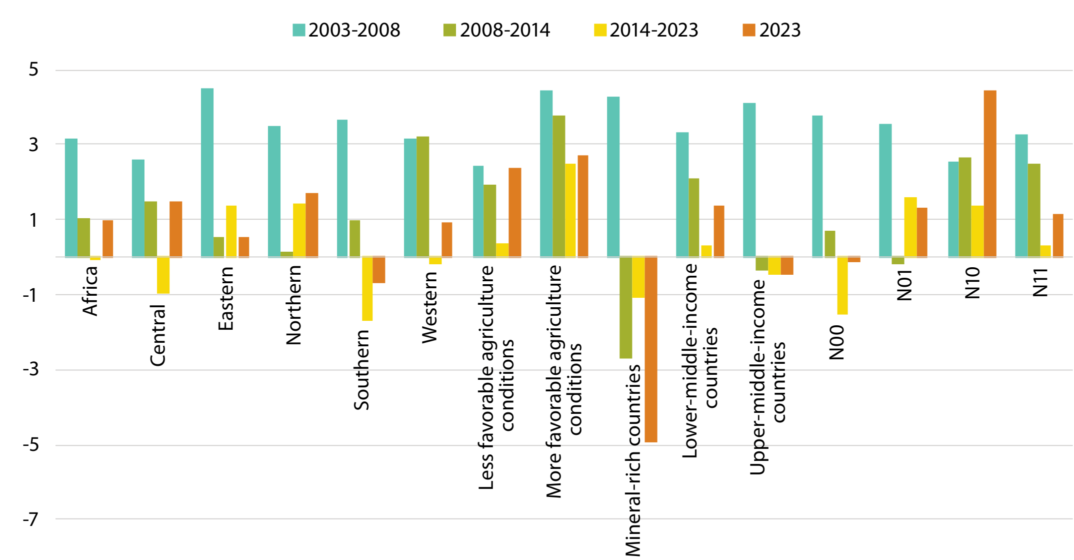
Wealth Creation

The Malabo period has been marked by global crises, including the COVID-19 pandemic and the Russia–Ukraine war, both of which have had a severe impact on Africa's economies. However, even before the onset of COVID-19 in 2020, economic growth had slowed from its previously robust pace during the early 2000s. During the Malabo period, economic growth fell slightly short of keeping pace with population growth, with a small decline in gross domestic product (GDP) per capita of 0.02 percent per year on average (Figure 13.2, Annex Table L1.1.1). This reflects uneven growth among the geographic regions, with annual average declines in GDP per capita of 0.9 percent and 1.7 percent in central and southern Africa, respectively, contrasting with growth of 1.3 percent and 1.4 percent in eastern and northern Africa, respectively. Western Africa, like the continent as a whole, experienced a small annual average decline in GDP per capita during the Malabo period. Growth paths also varied among economic categories: low-income countries with more favorable agricultural conditions showed relatively high increases in GDP per capita of 2.4 percent per year on average, contrasting with annual average declines of 1.0 percent in low-income, mineral-rich countries. Among the NAIP categories, countries with neither a first- nor a second-generation NAIP (N00 countries) fared the worst, with annual average declines of 1.5 percent; N01 and N10 countries saw increases in GDP per capita of greater than 1 percent per year while N11 countries saw smaller annual average increases of 0.3 percent. Self-selection may explain the difference. In an attempt to boost economic growth, countries with lower GDP growth rates may tend to have more consistent and frequent NAIPs than countries with higher GDP growth rates. A detailed causal analysis is required to explain these trends.

Africa continues to recover after the growth shocks of the past few years. Growth in 2023 was positive and higher than the 2014–2023 period average for nearly all country groupings. A notable exception is low-income, mineral-rich countries, with a large decline of 4.9 percent in 2023 compared with more moderate declines for the Malabo period as a whole. Africa as a whole saw GDP per capita growth in 2023 of 0.9 percent.

The level of GDP per capita in Africa as a whole stood at US$2,005.90[8] in 2023 (Annex Table L1.1.1), representing growth of around 25 percent since the

FIGURE 13.2—GROSS DOMESTIC PRODUCT PER CAPITA, CONSTANT 2015 US$, ANNUAL AVERAGE PERCENTAGE CHANGE, 2003–2023



Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

8 Unless stated otherwise, all dollar amounts in the chapter refer to constant 2015 US dollars.

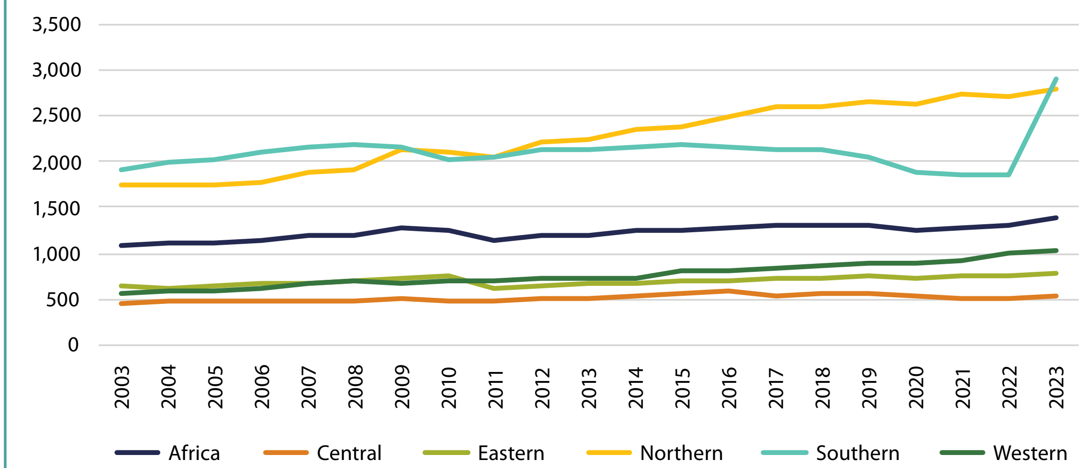
beginning of the CAADP period in 2003, but very little change since the beginning of the Malabo period. Average incomes vary widely across the continent, with GDP per capita in northern Africa more than twice the continental average and that in central Africa less than half the average. Among NAIP groups, countries with only a first-generation NAIP (N10 countries) have the lowest per capita incomes and countries with neither a first- nor a second-generation NAIP (N00 countries) have the highest. Nearly all N00 countries are either lower-middle-income or upper-middle-income countries, both of which have significantly higher GDP per capita than the other economic groups (despite negative growth in average incomes in upper-middle-income countries during the Malabo period).

A major component of GDP is household consumption expenditure, which measures total spending on goods and services to meet the household's consumption needs. Household consumption expenditure per capita displays similar trends as GDP per capita. During the Malabo period to date, average household consumption expenditure rose from $1,236.30 in 2014 to $1,341.10 in 2023, representing a small annual average increase of 0.7 percent (Figure 13.3, Annex Table L1.1.2). Household consumption expenditure increased in all geographic regions during the Malabo period, with the exception of central Africa, which showed a small annual average decrease. The largest growth in consumption expenditure was in western Africa at 3.5 percent per year on average. Patterns in consumption expenditure levels as of 2023 are similar to those for GDP per capita, with the highest spending levels in northern Africa and the lowest in central Africa. Among NAIP groups, countries with a second- but not a first-generation NAIP (N01 countries) have the highest household consumption expenditures, followed by N00 countries, with N10 countries showing the lowest levels (Annex Table L1.1.2).

Food and Nutrition Security

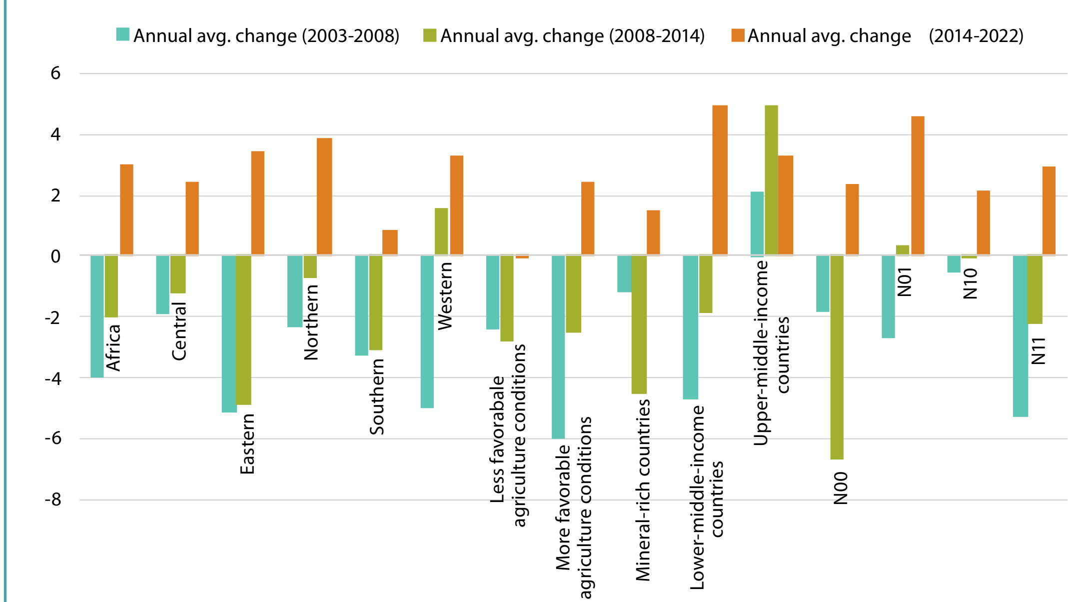
Improving food and nutrition security has long been a key development goal in Africa and remains an urgent concern in

FIGURE 13.3—ANNUAL HOUSEHOLD CONSUMPTION EXPENDITURE PER CAPITA, CONSTANT 2015 US$, 2003–2023



Source: ReSAKSS based on World Bank (2024) and ILO (2024).

FIGURE 13.4—PREVALENCE OF UNDERNOURISHMENT, ANNUAL AVERAGE PERCENTAGE CHANGE, 2003–2022



Source: ReSAKSS based on FAO (2024), World Bank (2024), and ILO (2024).

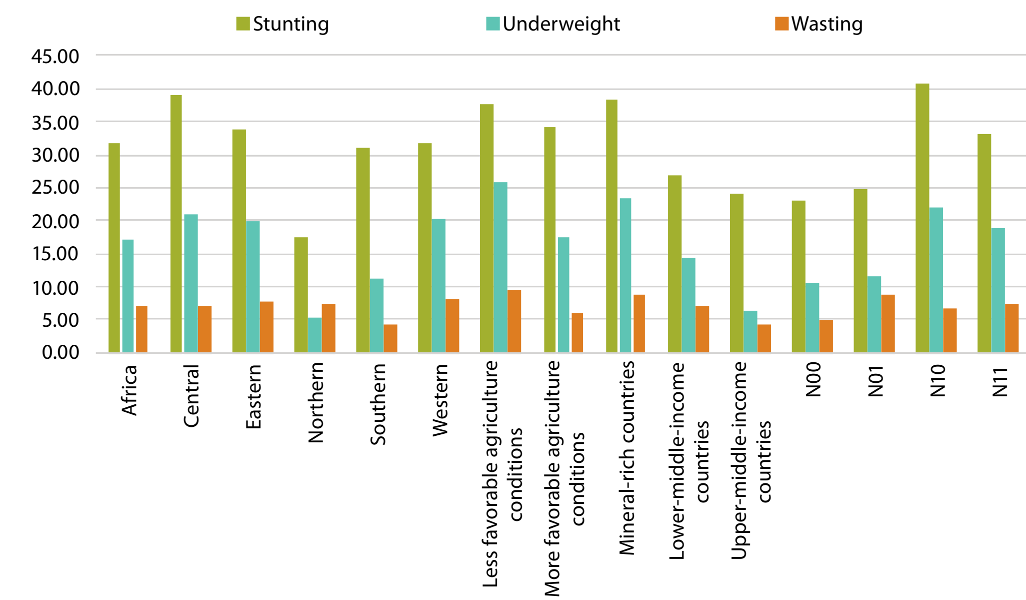
Note: N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

the current era of frequent crises. The prevalence of undernourishment, which measures the share of the population with caloric intake below the minimum requirement, has risen during the Malabo period, increasing by an average of 3.0 percent per year for the continent as a whole (Figure 13.4, Annex Table L1.2.1). Although the increase was more marked in some areas than others, nearly every country group examined showed increasing undernourishment during the Malabo period. The only exceptions are low-income countries with less favorable agricultural conditions, which showed a very slight decrease in undernourishment of 0.1 percent per year. The largest increases in the prevalence of undernourishment (greater than 4 percent) were seen in lower-middle-income countries and countries with a second-generation but not a first-generation NAIP (N01 countries). By geographic region, undernourishment grew the most in northern and eastern Africa and the least in southern Africa. These increases were in contrast with steady declines in undernourishment in the pre-Malabo period in nearly all country groups. The transition to rising undernourishment has been attributed to a number of factors, including the impacts of climate shocks, such as the 2015–2016 El Niño event that caused severe droughts in eastern and southern Africa; conflict in several areas of the continent that led to reduced food production; and reduced commodity prices that decreased purchasing power in some commodity-exporting countries (FAO 2017; AfDB 2017).

As of 2022, the prevalence of undernourishment was 20.0 percent at the continental level (Annex Table L1.2.1). The highest levels of undernourishment were found in countries with only a first-generation NAIP (35.3 percent) and in central African countries (29.6 percent), while the lowest rates were found in northern African countries (6.5 percent), upper-middle-income countries (9.6 percent), and countries with only a second-generation NAIP (14.2 percent). For Africa as a whole and for most country groupings, levels of undernourishment in 2022 were similar to those at the beginning of the CAADP period in 2003, as the increases during the Malabo period counteracted decreases in the earlier CAADP periods. However, some areas had more substantial declines in undernourishment, including eastern African countries and low-income countries with less favorable agricultural conditions, which showed declines of more than 8 percentage points between 2003 and 2022. In contrast, upper-middle-income countries showed a considerable increase over the entire CAADP period, from 4.9 percent in 2003 to 9.6 percent in 2022.

Like overall undernourishment, child undernourishment assessed through biometric measures remains severe in most of the continent. During the 2014–2022 period, rates of stunting, underweight, and wasting in children under five averaged 31.5 percent, 17.1 percent, and 7.0 percent, respectively (Figure 13.5; Annex Tables L1.2.2A, L1.2.2B, and L1.2.2C). By region, central Africa had the highest rate of stunting and underweight and northern Africa had the lowest. Patterns are somewhat different for wasting, with the highest rates found in western Africa and the lowest in southern Africa. Northern Africa differs from

FIGURE 13.5—PREVALENCE OF UNDERWEIGHT, STUNTING, AND WASTING IN AFRICA, PERCENTAGE OF CHILDREN YOUNGER THAN FIVE YEARS, 2014–2022 AVERAGE



Source: ReSAKSS based on World Bank (2024) and ILO (2024).

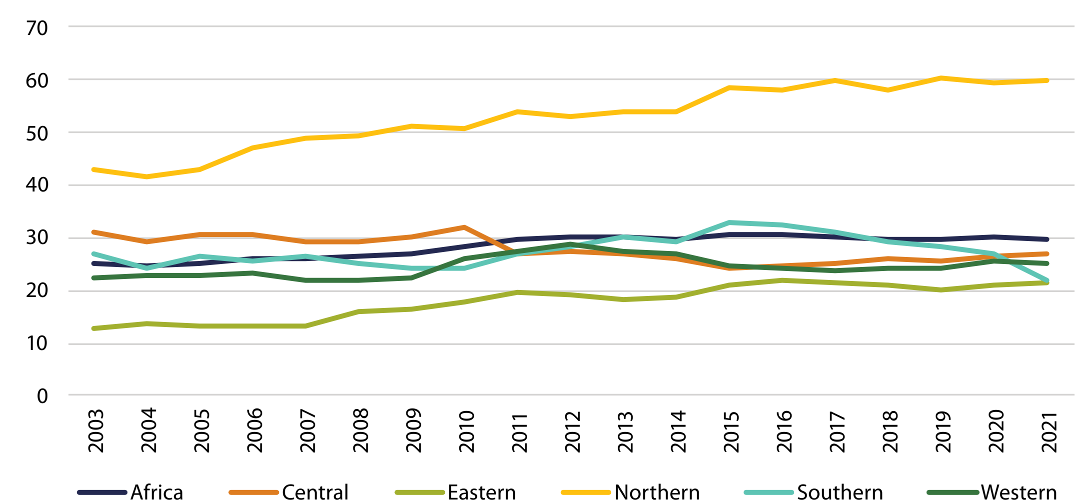
Note: N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

other country groupings in that the rate of wasting, at 7.4 percent, exceeded the rate of underweight, at 5.1 percent. In terms of economic groupings, low-income countries with less favorable agricultural conditions and low-income, mineral-rich countries had the highest rates of all three child malnutrition indicators during the Malabo period and upper-middle-income countries had the lowest. Among NAIP groups, N10 countries had the highest rates of stunting and underweight while N01 countries had the highest rates of wasting; N00 countries had the lowest rates of all child malnourishment indicators, reflecting the fact that nearly all N00 countries are upper- or lower-middle-income countries.

The prevalence of child undernourishment remains far above Malabo Declaration targets, which call for reducing the levels of stunting and underweight to 10 percent and 5 percent, respectively, by 2025. However, child stunting, underweight, and wasting have declined consistently during the Malabo period through 2022, avoiding so far the increases seen for the prevalence of undernourishment overall. The small but sustained decrease in child undernutrition despite broader food and nutrition security challenges may be related to the success of nutrition-specific interventions targeted to children, as well as improvements in healthcare and sanitation (IFPRI 2017). For Africa as a whole, rates of stunting, underweight, and wasting among children decreased by 1.5 percent, 1.9 percent, and 1.8 percent per year on average, respectively (Annex Tables L1.2.2A, L1.2.2B, and L1.2.2C). All three measures of child undernourishment decreased in all country groups, with the exception of wasting, which increased slightly in northern Africa and showed no change in upper-middle-income countries and N01 countries. Whereas stunting is an indicator of chronic undernutrition, wasting reflects shorter-term acute undernutrition and is sometimes associated with humanitarian emergencies or other crises. The relatively high rates of wasting in northern Africa are driven by Libya, Mauritania, and Egypt and may be partly related to instability as well as other factors. The future trajectory of child and overall undernourishment in Africa is uncertain, as the longer-term impacts of food price inflation experienced in many countries following the onset of the Russia–Ukraine war in 2022 remain to be assessed.

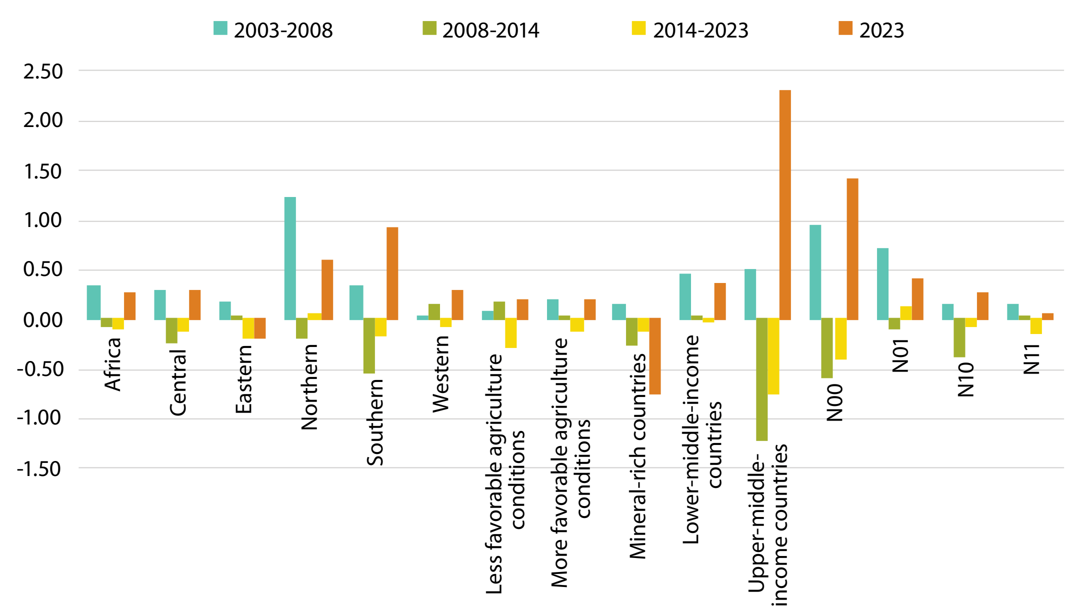
The cereal import dependency ratio expresses the share of total cereal supplies (including production and net imports) that are sourced from imports rather than domestic production. Although imports are an important part of countries' food supplies, a high import dependency ratio can reflect vulnerability to global market shocks. The cereal import dependency ratio for Africa as a whole increased moderately during the pre-Malabo CAADP period but has remained mostly steady during the Malabo period at around 30 percent (Figure 13.6, Annex Table L1.2.3). This represents a medium level of dependence according to the categorization used in the food import vulnerability index (FIVI) developed for the Food Security Portal by the International Food Policy Research Institute (IFPRI 2024). Dependency is highest in northern Africa, where it is also on the increase, growing from 53.9 percent in 2014 to 59.8 percent in 2021. Eastern Africa had the lowest dependency ratio throughout the period, but it is also increasing, while in southern Africa dependency fell

FIGURE 13.6—CEREAL IMPORT DEPENDENCY RATIO, PERCENTAGE OF TOTAL DOMESTIC CEREAL SUPPLY, 2003–2021



Source: ReSAKSS based on FAO (2024), World Bank (2024), and ILO (2024).

FIGURE 13.7—EMPLOYMENT RATE, PERCENTAGE OF LABOR FORCE AGES 15 TO 64 YEARS, ANNUAL AVERAGE PERCENTAGE CHANGE, 2003–2023



Source: ReSAKSS based on ILO (2024).
Note: The labor force refers to the share of the population that is either working or available for and seeking work.

throughout the period. As of 2021, all of Africa's geographic regions fell within the FIVI category of low import dependence, except for northern Africa with a very high import dependence. It should be noted that relatively high cereal import dependency ratios do not necessarily indicate food insecurity, as reflected by the fact that northern Africa has by far the highest import dependency but also the lowest rates of undernourishment and of most forms of child malnutrition (Figures 13.4 and 13.5).

Employment

Africa's employment rate, measured as a share of the labor force aged 15–64 years, declined slightly during the Malabo period at a rate of 0.1 percent per year (Figure 13.7, Annex Table L1.3.1A). Although this decline began prior to the COVID-19 pandemic, it accelerated in 2020 and continued in 2021 before employment began to rise again in 2022 (Collins, Tefera, and Wambo Yamdjeu 2023).

Among the country groups, only northern Africa and N01 countries showed slight increases in employment rates during the Malabo period. All other groups showed declines, with the largest decreases in upper-middle-income countries, N00 countries, low-income countries with less favorable agricultural conditions, and eastern African countries. Employment rebounded in most of these groups with rising rates between 2022 and 2023, especially in upper-middle-income countries and N00 countries, but employment rates in eastern Africa were still declining into 2023.

Employment as a percentage of the population over 15 (Annex Table L1.3.1B) showed broadly similar patterns to those of employment as a percentage of the labor force. All country groups showed declines in employment as a share of population during the Malabo period, including northern Africa and N01 countries, suggesting that the slight increases in employment measured as a share of the labor force in those groups (Figure 13.7) were associated with decreases in the size of the labor force as a share of the population.

In 2023, the employment rate as a share of the labor force was 90.6 percent in Africa as a whole (Annex Table L1.3.1A). Among geographic groups, western Africa had the highest rate (93.7 percent) and southern Africa the lowest (82.8 percent). When measured as a share of the entire population 15 and over, Africa's employment rate was recorded at 58.5 percent in 2023, with significant differences across geographic regions (Annex Table L1.3.1B). Eastern and central Africa had the highest employment rates of 68.2 percent and 63.9 percent, respectively, while northern Africa had by far the lowest rate of 39.7 percent. The difference between the two employment rates reflects differences in the labor force of each region as a share of the population. Among economic groups, low-income countries with more favorable agricultural conditions have the highest employment rates, both as a share of the labor force and of the population, likely reflecting the dominance of agriculture as a source of employment in Africa.

Poverty

Reducing poverty in Africa is a key goal of the Malabo Declaration as well as

Agenda 2063 and other development frameworks. Poverty has fallen throughout the CAADP period, although progress has been uneven and has slowed during the Malabo period compared with earlier years. The poverty headcount ratio at the international poverty line of USPPP$2.15 (2017 purchasing power parity [PPP]) decreased modestly during the Malabo period at an annual average of 0.6 percent (Annex Table L1.3.4). As of 2021, the last year for which data are available, the poverty headcount ratio stood at 30.0 percent for Africa as a whole—a significant decrease from 2003's 41.2 percent, but only a slight decrease from the 2014 level of 31.7 percent. Eastern, southern, and central Africa had poverty rates above the continental average; poverty in western Africa was slightly below the continental average, with the lowest poverty rate of 0.8 percent in northern Africa. Among economic groups, mineral-rich countries had by far the highest poverty rate of 64.3 percent in 2021, with the lowest rates in lower- and upper-middle-income countries (Annex Table L1.3.4). Among the NAIP categories, N10 countries had the highest poverty (62.1 percent) and N01 countries had the lowest (15.6 percent).

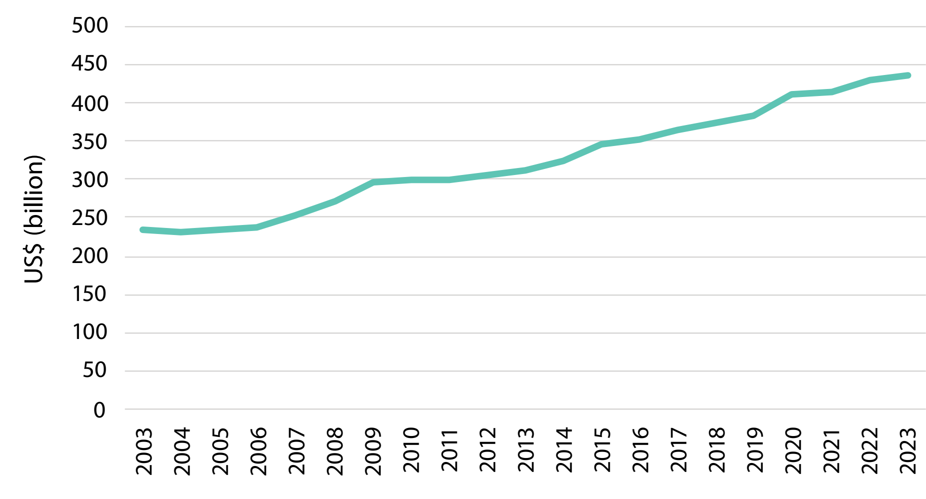
Whereas the poverty headcount ratio measures the total share of the population under the international poverty line, the poverty gap (Annex Table L1.3.3) measures the average percentage distance below the poverty line for the entire population, serving as an indicator of both the incidence of poverty and the severity of poverty. As of 2021, the poverty gap was 10.5 percent for the continent as a whole, with higher rates in eastern and southern Africa of 15.8 percent in both regions, followed by central Africa; the poverty gap was the lowest by far in northern Africa at 0.2 percent. Eastern and southern Africa were also the only two geographic regions in which the poverty gap increased during the Malabo period. Among economic groupings, the poverty gap was by far the highest in low-income, mineral-rich countries, at 31.0 percent, and lowest in upper- and lower-middle-income countries. Among NAIP groups, the poverty gap was highest in countries that had developed a first-generation but not a second-generation NAIP.

CAADP Results Framework Output (Level 2) Indicators: Agricultural Transformation and Sustained Inclusive Agricultural Growth

Agricultural Production and Productivity

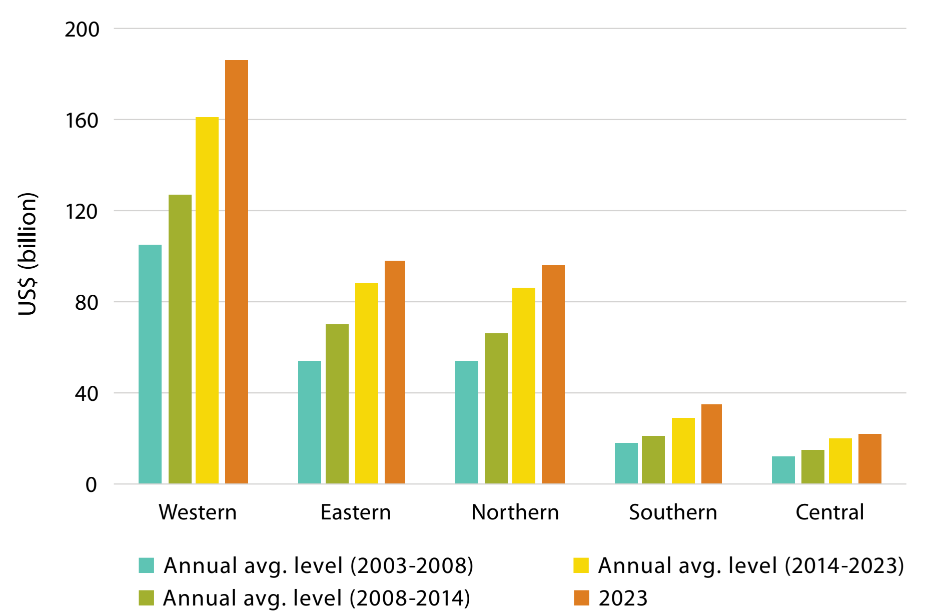
Looking at its contribution to employment, GDP, external trade, and food

FIGURE 13.8—AGRICULTURE VALUE ADDED (CONSTANT 2015 US$, BILLION)—AFRICA



Source: ReSAKSS based on World Bank (2024) and FAO (2024).

FIGURE 13.9—AFRICAN AGRICULTURE, AVERAGE ANNUAL VALUE ADDED, US$ BILLIONS (CONSTANT 2015 US$), BY TIME PERIOD AND GEOGRAPHIC REGION



Source: ReSAKSS based on World Bank (2024) and FAO (2024).

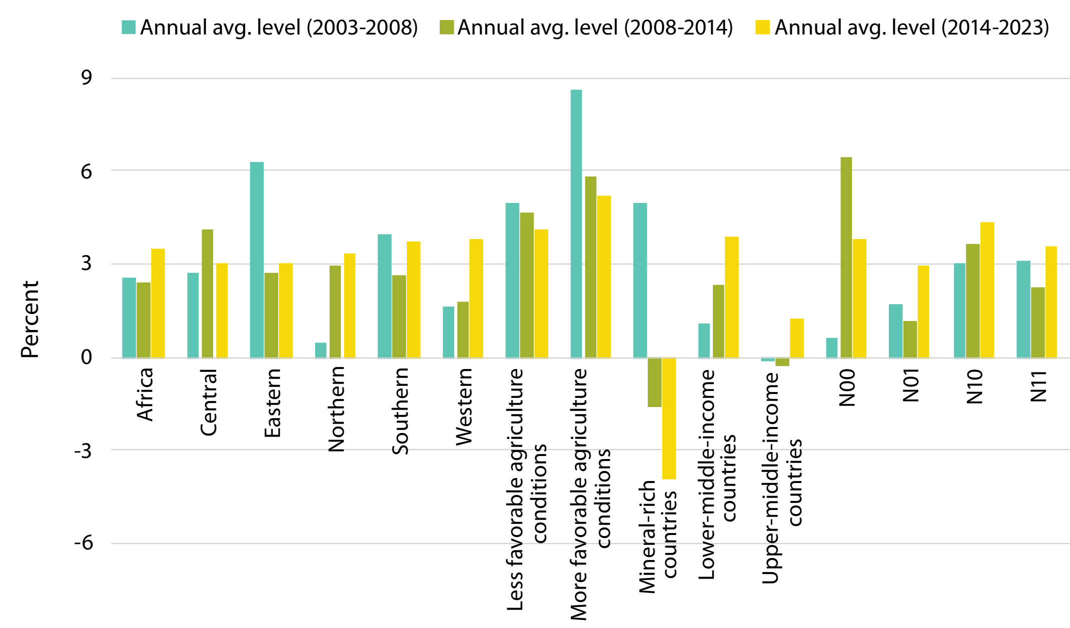
security, agriculture is the most critical sector in Africa and plays a significant role in the countries of the continent. The last two decades saw improvement in the agriculture sector, although there were differences in performance at the regional and country levels. For Africa as a whole, agriculture value added almost doubled during the CAADP period. It increased from $235.4 billion in 2003 to $437.3 billion in 2023 (Figure 13.8).

Viewed from a regional perspective, the western Africa region held the highest agriculture value added during the whole CAADP period with a share of 42 percent of the value added in Africa during the Malabo period (2014–2023). This shows that western Africa is the major contributor of agriculture value added in the continent. This is followed by eastern Africa and northern Africa at 22.8 percent and 22.4 percent, respectively. The shares for southern and central Africa are smaller at 7.4 percent and 5.4 percent, respectively, for the same period. Figure 13.9 shows that all geographic regions recorded consistent increases in agriculture value added during the CAADP subperiods.

For Africa as a whole, agriculture value added recorded positive growth throughout the CAADP period. But growth during the Malabo period was higher than during the Maputo period. That is, value added grew at 2.57 percent and 2.41 percent during the 2003–2008 and 2008–2014 periods, respectively, before jumping to 3.46 annual average growth during 2014–2023. Except for the mineral-rich countries and upper-middle-income countries that recorded negative growth rates in agriculture value added, all of the other country subgroups produced positive growth rates over the whole CAADP subperiods. Higher growth rates were recorded by the countries with more favorable agriculture conditions, although the growth rate slowed down in the recent subperiods. A similar pattern was also observed in the countries with less favorable agriculture conditions (Figure 13.10). None of the different subgroups was able to meet the 6 percent CAADP target during the Malabo period (2014–2023).

Some nine countries managed to record an annual average growth rate of more than the CAADP 6 percent target during the 2014–2023 period, including Guinea, Niger, Ethiopia, Senegal, Rwanda, Seychelles, Gabon, Kenya, and Gambia. Of those, only Ethiopia and Rwanda managed to surpass the 6 percent CAADP target during 2008–2014. Another six countries—Angola, Algeria, Mali, Sao Tome and Principe, Sierra Leone, and Tanzania—were able to meet the CAADP 6 percent target in that subperiod but then saw their annual average growth decelerate in the Malabo period (Figure 13.11).

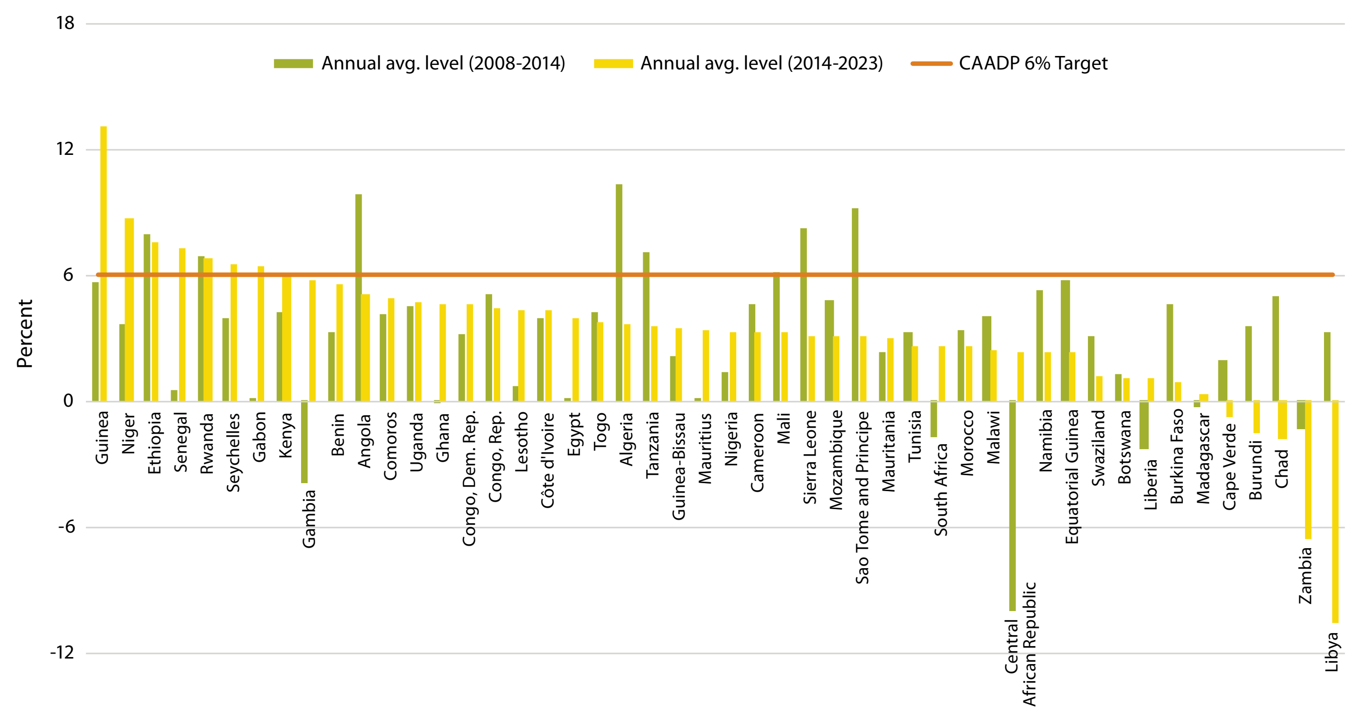
FIGURE 13.10—AGRICULTURE VALUE ADDED, ANNUAL AVERAGE GROWTH, PERCENTAGE, 2003–2023



Source: ReSAKSS based on World Bank (2024) and FAO (2024).

Sustainable labor and land productivity are central to the continuous growth of the agriculture sector. Such developments have several implications including for food price stability, improving food security, and also reducing poverty and malnutrition among rural households. Measured by agriculture value added per worker, *agricultural labor productivity* in Africa increased from an annual average of $1,410.1 recorded during the initial CAADP subperiod (2003–2008) to $1,554.8 in 2008–2014 and further up to a yearly average of $1,769.6 during the Malabo period (2014–2023). Similar increasing trends were observed in almost all of the subgroups despite notable variation (Annex Table L2.1.3). That is, labor productivity remained the highest in northern Africa followed by the lower-middle-income countries, while it was the least in central

FIGURE 13.11—NATIONAL AGRICULTURAL VALUE ADDED, ANNUAL AVERAGE GROWTH, PERCENTAGE, BY TIME PERIOD



Source: ReSAKSS based on World Bank (2024) and FAO (2024).

Africa and the group of countries that have formulated a first-generation NAIP only (N10).

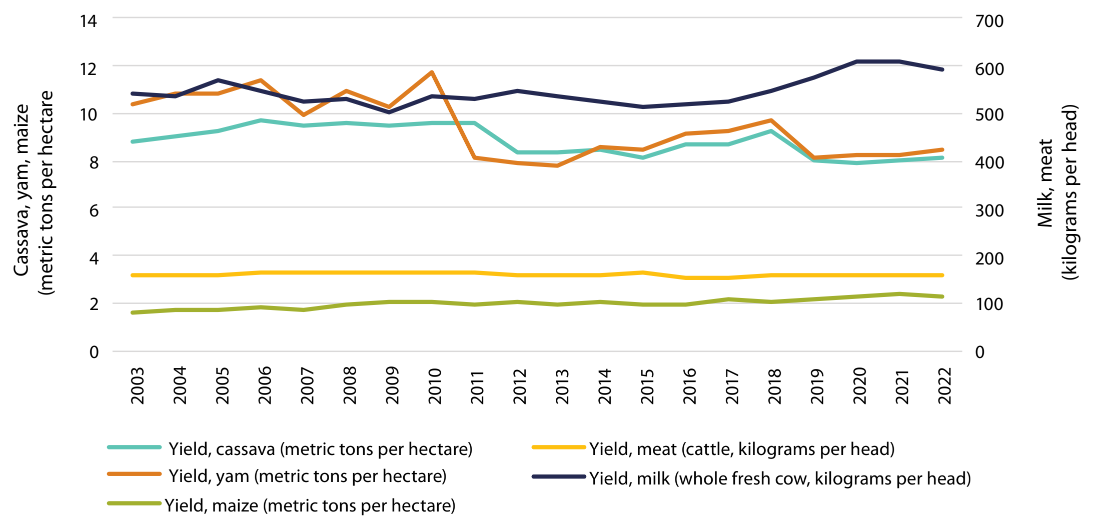
Land productivity, measured by agriculture value added per hectare of arable land, consistently increased for Africa as well as for the different subgroups. For Africa as a whole, land productivity increased from an annual average of $232.6 in 2003–2008 to annual averages of $282.1 and $356.5 in 2008–2014 and 2014–2023, respectively. The subgroups that recorded the highest land productivity are northern Africa, western Africa, and the lower-middle-income countries, recording more than $600 on average per annum during the Malabo period (2014–2023). On the other hand, agriculture land productivity remained the least in southern Africa and the upper-middle-income countries, recording an annual average of less than $100 throughout the whole CAADP period (Annex Table L2.1.4).

Cassava, yam, maize, cattle meat, and cow milk are the five major agricultural commodities in Africa, accounting for 28.9 percent of the continent's total agriculture production during 2003–2022. As shown in Annex Tables L2.1.5A, L2.1.5B, L2.1.5C, L2.1.5D, and L2.1.5E, growth for these major agriculture commodities has not been uniform over the CAADP subperiods. Except for maize, which exhibited a positive growth rate consistently throughout the different CAADP subperiods, the commodities recorded a positive annual average rate of growth in one subperiod and a negative growth rate in the other. For Africa as a whole, the annual average yield for cassava, yam, and maize was 8.3, 8.7, and 2.1 metric tons per hectare during the Malabo period (2014–2022). For the same period, yield for meat and milk was 159 and 556.4 kilograms per head. Africa's yield levels are much lower than those of other regions of the world. According to FAOSTAT (FAO 2024), the annual average yield in Asia for the period 2014–2022 was 21.6, 18.5, and 5.4 metric tons per hectare for cassava, yam, and maize, respectively. Such performance in other regions shows that Africa is far behind and must improve yields for its priority commodities. The trend in yield for the whole CAADP period is shown in Figure 13.12.

Intra-African Agricultural Trade

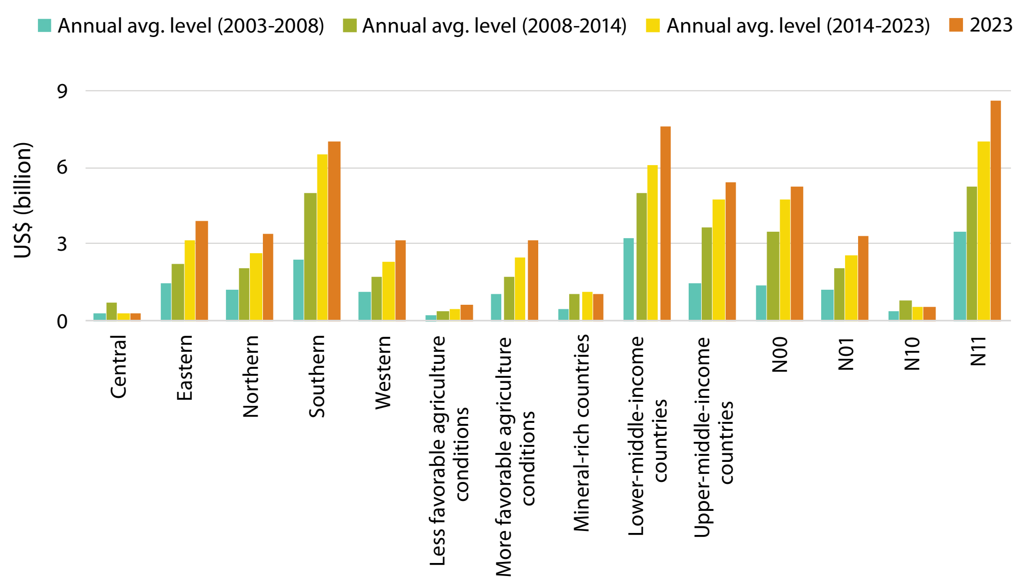
Africa saw a continuous increase in intra-African agricultural trade throughout the CAADP period. *Intra-African agricultural exports* grew from an annual average of $6.4 billion in 2003–2008 to $11.6 billion in 2008–2014 and further

FIGURE 13.12—YIELD FOR THE FIVE MAJOR COMMODITIES FOR AFRICA, 2003–2022



Source: ReSAKSS based on FAO (2024).

FIGURE 13.13—INTRA-AFRICAN AGRICULTURAL EXPORTS, CONSTANT 2015 US$ BILLIONS, BY TIME PERIOD AND COUNTRY GROUPING



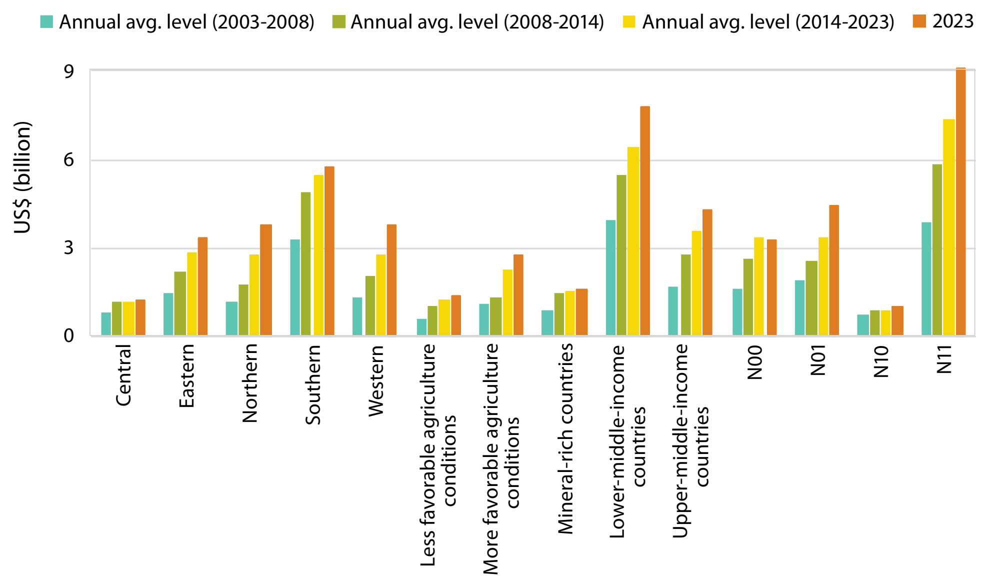
Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

to $14.8 billion during 2014–2023. By 2023, intra-African agricultural exports had reached $17.6 billion (Annex Table L2.2.1A). The performance recorded during the Malabo period was far behind the commitment to triple intra-African trade in agricultural commodities and services by 2025. Between 2014 and 2023, Africa as a whole was able to increase intra-African trade by 36.2 percent only, far less than the commitment made in 2014 to boost trade. The successive BRs also show that since the second BR Africa has been off track in meeting the Malabo goal of boosting intra-African trade in agricultural commodities and services by 2025 (see Table 13.3). From the perspective of country groups, the results show that intra-African agricultural exports are dominated by southern Africa, lower-middle-income countries, and the countries that have formulated both generations of NAIPs (N11).

As Figure 13.13 shows, almost all of the country subgroups exhibited increases in intra-African agricultural exports during the successive subperiods. Exceptions were central Africa and the group of countries that have formulated a first-generation NAIP only (N10), which recorded a decline during the Malabo period (2014–2023) compared with the earlier period. Intra-African agricultural exports are notably dominated by a few countries on the continent. Between 2014 and 2023, South Africa alone accounted for 25.8 percent of the trade, followed by Egypt (8 percent) and Uganda (6.2 percent). Those three countries accounted for 40 percent of total intra-African agricultural exports during the Malabo period.

For the different subgroups, intra-African agricultural imports improved during the CAADP period. For Africa as a whole, they increased from an annual average level of $7.9 billion recorded during the early CAADP subperiod (2003–2008) to $11.9 billion and $14.9 billion in 2008–2014 and 2014–2023, respectively (Annex Table L2.2.1B). As Figure 13.14 reveals, dominant players in intra-African agricultural imports are the southern Africa region, the lower-middle-income countries, and the group of countries that have embarked on both the first and second generations of NAIPs (N11).

FIGURE 13.14—INTRA-AFRICAN AGRICULTURAL IMPORTS, CONSTANT 2015 US$ BILLIONS, BY TIME PERIOD AND COUNTRY GROUPING



Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

Despite observed improvements in imports within Africa, studies show that Africa remains a net importer of agricultural goods with total imports of around $80 billion (FAO and AUC 2021). This implies that the share of intra-African imports in the total import bill is around 20 percent. Moreover, the growth in imports from the rest of the world is faster than the growth in intra-African imports in recent periods (Olivetti et al. 2023). Furthermore, intra-African agricultural trade imports are dominated by a few countries, mainly the countries in the southern Africa region. Of the 10 leading countries in intra-African agricultural trade, five are from southern Africa. The leading five countries during the Malabo period were South Africa (7.1 percent), Egypt (5.2 percent), Namibia (5.2 percent), Botswana (4.8 percent), and Zimbabwe (4.7 percent).

CAADP Results Framework Input (Level 3) Indicators: Strengthening Systemic Capacity to Deliver Results

Capacities for Agriculture and Food Security Policy Design and Implementation

Progress in the implementation of actions to strengthen systemic capacity for agriculture and food-security policy planning and implementation under CAADP is presented in Annex Table L3(b). Accomplishments as of September 2024 were as follows:

- 45 countries had formulated new or revised second-generation NAIPs through inclusive and participatory processes;
- 28 countries had inclusive institutionalized mechanisms for mutual accountability and peer review—mainly JSRs;
- 36 countries were implementing evidence-based policies;
- 31 countries had functional multisectoral and multistakeholder coordination bodies—mainly agricultural sector working groups; and
- 22 countries had successfully undertaken agriculture-related public–private partnerships to boost specific agricultural value chains.

These figures are based on countries' self-reporting or the assessment of country experts. Determining the values for several of these measures required subjective judgments on the quality of capacities and processes, so they may be subject to change.

Government Expenditure on Agriculture

Agriculture is the leading economic sector in most countries in Africa in terms of its contribution to national GDP; it has many backward and forward linkages with other sectors such as manufacturing and service. It contributes significantly to employment and foreign exchange earnings through cross-border trade. In the majority of countries, the sector contributes significantly to overall economic growth. Public spending in the sector is critical for providing public goods and services that support development and growth of the sector and for crowding in essential private sector investment. In recognition of the importance of public expenditure in agriculture, the CAADP framework set a target of 10 percent of total government spending to be allocated to the agriculture sector annually. In level terms, average annual government agriculture expenditure increased from $13.3 billion on average between 2003 and 2008 to $14.5 billion between 2008 and 2014 to $17.5 billion in the period from 2014 to 2023.

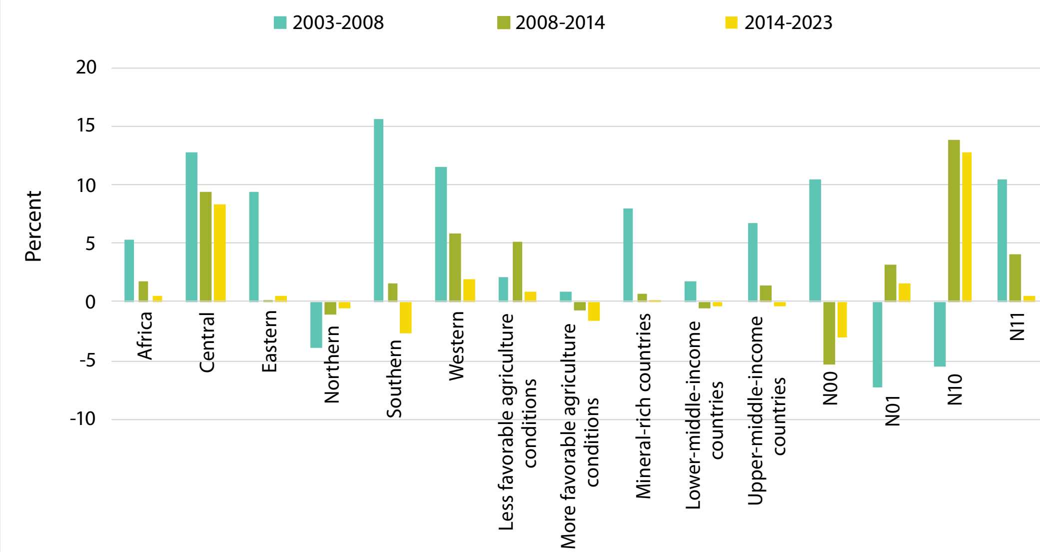
A breakdown of government agriculture expenditure by country subgroup shows notable variation in the level of such spending. Among countries classified by income, middle-income countries accounted for 62.3 percent of total public spending on agriculture in Africa between 2014 and 2023. For the same period, the highest share of government spending on agriculture, 62 percent, occurred in the group of countries that had formulated both generations of NAIP (N11).

Growth in government agriculture expenditure in Africa was the highest in the early CAADP period but declined in subsequent subperiods. The average annual growth rate in government agriculture spending was 5.3 percent between 2003 and 2008 but declined to 1.5 percent between 2008 and 2014 and fell further to a growth rate of just 0.4 percent between 2014 and 2023. As Figure 13.15 shows, a similar downward trend is observed for most of the country subgroups, particularly during the 2014–2023 subperiod.

The share of government agriculture expenditure in total government spending remained modest over the last two decades. For Africa as a whole, the share was 3.6 percent on average between 2003 and 2008 before declining to 2.6 percent for the 2008–2014 period and then improving moderately between 2014 and 2023, reaching 2.8 percent.

Marked differences in the share of agriculture expenditure in total government expenditure were seen among country subgroups during the review period (Annex Table L.3.5.2).

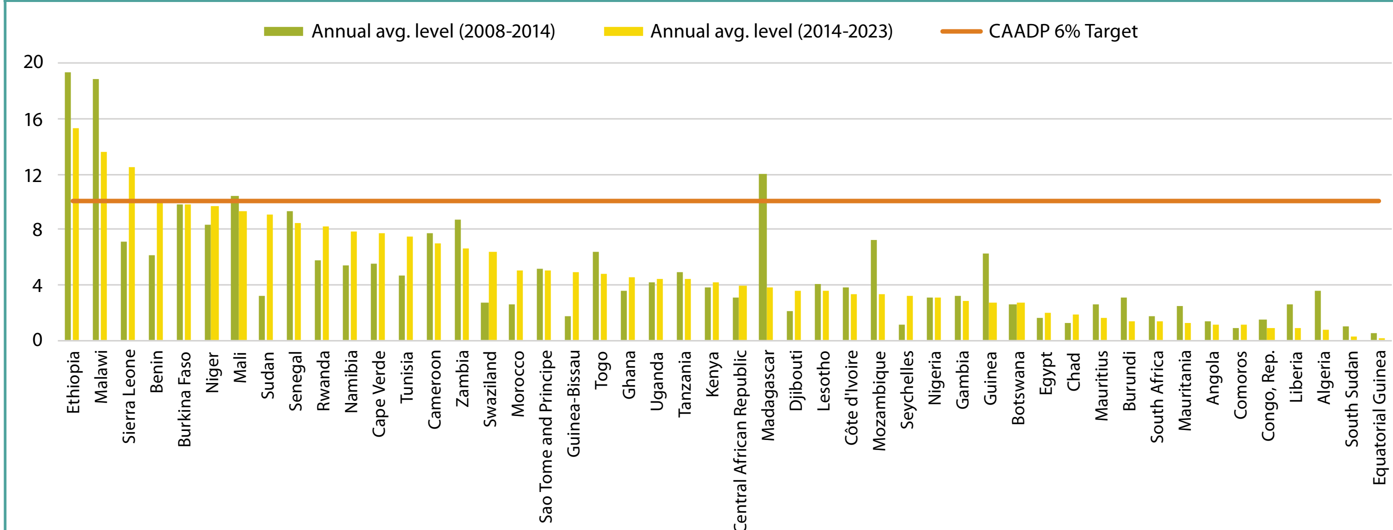
FIGURE 13.15—GOVERNMENT AGRICULTURE EXPENDITURE, AVERAGE ANNUAL PERCENTAGE CHANGE, 2003–2023



Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national government sources.

Note: N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

FIGURE 13.16—SHARE OF GOVERNMENT AGRICULTURE EXPENDITURE IN TOTAL GOVERNMENT EXPENDITURE, PERCENTAGE, 2008–2023, BY COUNTRY

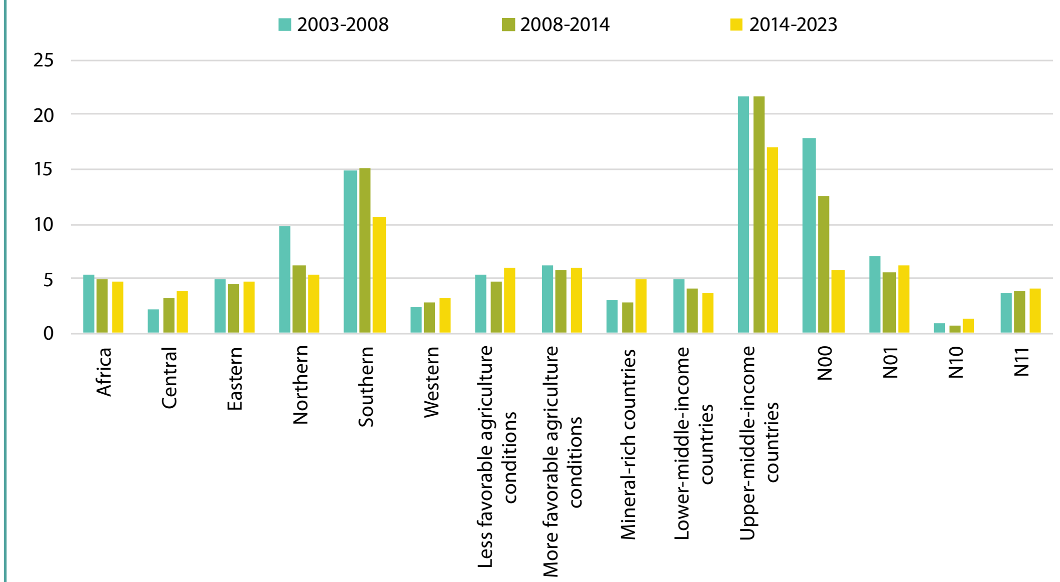


Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national government sources.

The highest share was observed among the lower-income countries with less favorable agricultural conditions and the lower-income countries with more favorable agricultural conditions in all three subperiods. Among geographic regions, eastern Africa had on average the highest share of total government expenditure made up by agriculture expenditure.

At the country level, agriculture expenditure as a share of total government spending varied notably across Africa, with very few countries consistently allocating a high share of total public spending to agriculture (Figure 13.16). Only Ethiopia and Malawi consistently met the CAADP 10 percent budget target throughout the 2008–2023 period. The performance of other countries was much less consistent over time. Madagascar and Mali met the 10 percent CAADP target for the 2008–2014 period. Sierra Leone and Benin achieved the 10 percent budget target during the 2014–2023 period. For the same period, Niger, Burkina Faso, Mali, and Sudan allocated more than 9 percent of their public spending to agriculture, close to the CAADP 10 percent budget target. Overall, the low level of public investment in agriculture is a challenge that countries need to address. Given its critical role in spurring economic growth, reducing poverty, and ensuring food security and employment, public investment in agriculture needs to be increased.

FIGURE 13.17—GOVERNMENT AGRICULTURE EXPENDITURE AS A SHARE OF AGRICULTURE VALUE ADDED, AVERAGE, PERCENTAGE, 2003–2022



Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national government sources.

Note: N00, N01, N10, and N11 categories refer to the presence or absence of first- and second-generation national agriculture investment plans (see footnote 6).

The intensity of government spending in agriculture proxied by the ratio of government agriculture expenditure relative to agricultural GDP (i.e., agriculture value added) has recorded a marginal decline over the 2003–2023 period. From a continental perspective, Africa's agriculture spending as a share of agriculture GDP averaged 5.3 percent for the 2003–2008 period, 4.8 percent between 2008 and 2014, and 4.6 percent between 2014 and 2023 (Figure 13.17). The performance for country subgroups was mixed—some groups showed an increasing trend while a declining trend was observed for a few others (Annex Table L.3.5.3). Over the review period, public spending on agriculture relative to the size of the country's agriculture sector was the highest for upper-middle-income countries and the southern Africa region followed by the group of countries that are yet to embark on a NAIP (N00).

Conclusion

As this chapter shows, the continent has made limited progress in advancing CAADP implementation, particularly in achieving CAADP BR goals and targets. For example, of the 49 AU Member States that participated in the fourth BR in 2023, not a single country is on track to achieve the Malabo commitments by 2025. Therefore, going into the next decade of CAADP, concerted effort is required to strengthen CAADP implementation capacities at the country and regional levels, including through embedding NAIPs in country-planning and country-budgeting cycles and enhancing interministerial and intercountry coordination.

The review of progress also demonstrates that although Africa has made important progress over the CAADP period in many areas, the pace of progress decelerated significantly during the Malabo Declaration period for several key development goals. For example, average incomes have changed very little from their 2014 levels, and poverty has declined only slightly. Progress in reducing hunger has been mixed, as child malnutrition has shown small but steady declines, but undernourishment among the population at large has increased during the Malabo period. Although the COVID-19 pandemic in 2020 and the onset of the Russia–Ukraine war in 2022 have presented severe challenges, progress toward many of the CAADP and Malabo goals had already slowed prior to those shocks. In the coming years, the continent will need to both sustain the recovery from recent crises and recapture the growth momentum of the earlier CAADP period.

The CAADP period saw Africa make steady progress in improving agriculture value added and labor and land productivity. For the sector to contribute more toward addressing food insecurity, malnutrition, rural unemployment, and so forth, agricultural productivity needs to increase substantially together with improved supporting and enabling infrastructure across the whole value chain.

Africa needs to do more and better in improving trade within the continent. The introduction of the African Continental Free Trade Area (AfCFTA) agreement is one of the major policy reforms adopted at the continental level that can be leveraged. In this regard, Africa should address tariff and nontariff barriers as well as improve trade facilitation measures to spur intracontinental trade. This has the potential to substantially increase such trade from the current 20 percent level. Leveraging AfCFTA will bring new trade opportunities, and the continent can gain from export diversification including agro-processing of food products.

Very few countries have met the CAADP target to spend at least 10 percent of total public expenditure on the agriculture sector. In addition, agriculture spending relative to agriculture GDP is low and has been declining since 2003. Public expenditure is essential for unlocking the sector's potential, driving productivity growth, and reducing poverty. Since public resources are limited, it is also critical to efficiently allocate available resources to the subsectors with the highest productivity growth potential and poverty reduction effects. Therefore, the generation and use of evidence in formulating strategies and programs is important to inform prioritization and resource allocation. Strengthening and deepening national-level accountability mechanisms such as the joint sector reviews is essential for monitoring policy implementation, learning, and reviewing. Effective JSRs must be underpinned by strong data management systems and strong in-country analytical capacities that are connected to policymaking processes.

The review of progress we present in this chapter has highlighted the significant variation in Africa's performance across years and across country groups in terms of geographic region, economic characteristics, and engagement in the CAADP process. A detailed examination of the factors contributing to diverging performance is beyond the scope of this chapter. Previous analyses of CAADP's impacts on Africa's development goals have shown both positive and mixed effects. For example, Benin (2016) found that CAADP had a positive impact on agricultural production and productivity growth, but mixed or limited impacts on other outcome areas. Ulimwengu, Tefera, and Wambo Yamdjeu (2023) found that whereas commitment to CAADP principles and values and progress in CAADP implementation had positive impacts in several areas, such efforts did not consistently contribute to positive outcomes, likely due in part to the complex effects of policies in different country contexts and the impacts of recent global and local shocks. As Africa embarks on the post-Malabo era, there is an evident need for further detailed causal analyses to explain past trends and guide the next phase of CAADP implementation.

CHAPTER 14

Conclusion

Getaw Tadesse, Katrin Glatzel, and Moumini Savadogo

African agrifood systems face several challenges and threats, both emerging and existing, that require concerted action and targeted policymaking by African governments and their partners. The 2024 edition of the Annual Trends and Outlook Report (ATOR) explores the challenges posed by the climate crisis to agrifood systems and the opportunities offered by a transition to a bioeconomy to mitigate and adapt to the adverse impacts of climate change. This edition of the ATOR seeks to support the development and subsequent implementation of the Comprehensive Africa Agriculture Development Programme (CAADP) through the renewed and updated post-Malabo CAADP agenda.

The chapters presented in this report highlight priority areas of action, including the need for an integrated policy approach to mitigate and reverse the adverse effects of climate change. The chapters' authors also argue for expanded investment in the bioeconomy to leverage biotechnology, agricultural waste, and renewable resources and enhance value addition and diversify income streams for farmers and rural communities. More importantly, the report highlights the win-win relationship between climate action and the expansion of the bioeconomy, with lessons from the continent and beyond. It also stresses the urgency of accelerating the implementation of national, continental, and regional climate change initiatives.

Specifically, the following insights and recommendations are presented in this edition of the ATOR:

Convergence of climate change and bioeconomy agendas: The chapter examines the linkages between the two pressing agendas of climate change and the bioeconomy. It discusses the major research concern of crafting bioeconomy opportunities to help African countries build resilience against climate change and other environmental risks. The chapter stresses the co-benefits that countries can obtain if they are able to link these two agendas both systematically and structurally. Transitioning to a bioeconomy through clear strategies that are aligned with climate change targets and priorities requires upscaling investments in new technologies; creating a conducive environment to enable emerging companies to innovate; providing the training and education needed to drive a bioeconomy transition; and cooperating across borders, between regions, and with other continents, all while adapting to climate change.

Diverse impacts of climate change on macroeconomies and agrifood systems: The impacts of climate change on African economies are diverse, with far-reaching implications for economic growth, unemployment, and poverty and food insecurity. The ability of agrifood systems to prevent, anticipate, absorb, adapt, and transform rapidly in the face of climate shocks and stresses depends on their stage of development. The three types of agrifood systems, which include traditional, modern, and transitional systems, are affected by climate change differently and thus require different strategies to adapt to and mitigate adverse effects.

Technology-based measurement and analysis of greenhouse gas emissions: Measuring greenhouse gas (GHG) emissions and stocks has become an important policy agenda, not only to track progress in reducing GHG emissions committed under nationally determined contributions (NDCs) but also to strategize mitigation interventions in African agrifood systems. This report presents new insights on how to estimate the concentration of methane in the atmosphere using data from geographic information systems and remote-sensing satellites across the continent. The estimation shows that the amount of methane emitted varies significantly between countries, land uses, and seasons. The results further reaffirm the significant contribution of agriculture to methane emissions in Africa and the significant variation of atmospheric methane levels according to sowing, growing, and harvesting seasons, with more pronounced methane emissions during the harvesting season.

Spatial distribution of climate risk exposure and vulnerability: The analysis of environmental risks associated with climate change in Africa reveals significant and varied impacts across the continent, highlighting several critical areas that require immediate attention and strategic intervention. The evaluation indicates a notable increase in temperatures across various regions, particularly in southern, eastern, and parts of western Africa. Precipitation anomalies reveal areas with significant deviations from historical rainfall patterns. The assessment also reveals significant spatial variations and increased risk of vegetation cover depletion and incidence of droughts. Africa is the continent most vulnerable to health impacts from climate change, with 63 percent of the most at-risk countries located there, including Burundi, Eritrea, Ethiopia, Gabon, Madagascar, and Niger. The chapter also sheds light on vulnerability to climate change using case studies from Rwanda and Senegal. The two case studies reveal that household vulnerability is largely attributable to the inability of households to adapt to climate shocks.

Sensitivity of agricultural commodities to climate stresses: The study presented in this chapter shows significant variation in the climate stress sensitivity of agricultural commodities, indicating that agricultural development efforts could be redirected toward crops that are less sensitive to shocks. The study found that some crops—including maize, sorghum, and soybeans—will see either a greater production boost or a lower loss in Africa than in the rest of the world. Groundnuts and rice will do modestly worse in Africa than in the rest of the world, but wheat and potatoes will suffer large losses that are much greater than those seen in the world as a whole. This finding raises crucial policy concerns about whether countries should focus on less-sensitive crops or invest more in sensitive crops and generate heat- and drought-tolerant varieties. However, policy choices between intensifying less-sensitive crops and/or adapting sensitive crops must consider the contexts, feasibility, and long-term strategic objectives of each country.

Effectiveness of climate adaptation actions in building agrifood system resilience: Consistent with global and continental initiatives, African countries have adopted several policies and strategies to combat the adverse effects of climate change. An assessment to explore the progress made in building resilience and the effectiveness of key climate-smart interventions across the continent reveals that, despite noteworthy advancements in developing climate change initiatives, African agriculture remains susceptible and insufficiently resilient to climate shocks. Approximately 4 out of 10 agricultural households in Africa remain vulnerable to climate disruptions. Moreover, the shift away from agriculture and the proportion of public expenditure allocated to the sector is weakly correlated with enhancements to agricultural resilience. Climate-smart interventions such as irrigation, sustainable land management, and agricultural insurance have long been advocated as ways to enhance climate adaptation, but they cover a small amount of arable land and few farmers, leading to insignificant impacts on resilience-building. Such limited coverage and insignificant effects are caused by challenges related to insufficient climate finance, inability to scale best practices, and vague and ineffective climate governance systems.

Circular bioeconomy to enhance nutrition outcomes: By fostering efficient resource use and waste reduction, a circular bioeconomy can contribute to more resilient food systems that support both people and the planet. It serves as a promising strategy to address the complex challenges of nutrition and sustainability in Africa. The chapter assesses areas where the circular bioeconomy can be enhanced to overcome the challenges of malnutrition in the continent. The study reveals that in regions with high insect consumption, insect farmers should be encouraged to liaise with food producers to use any generated biowaste in their insect farming businesses. Aquaponics should be promoted in countries where fish farming is prevalent, such as Egypt, Ghana, Kenya, Nigeria, and Uganda. It can also be implemented in drought-prone regions of Africa to ensure water conservation and to boost the supply of nutrient-rich vegetables and fish. However, realizing this potential fully will require concerted efforts to overcome existing barriers, particularly in terms of policy, community engagement, and technological innovation.

Bioeconomy in global agrifood systems: The experiences of expanding the bioeconomy in selected African, Asian, and Latin American countries (Ghana, Namibia, Uganda, Thailand, and Brazil) clearly demonstrate the importance of elevating the bioeconomy as a top policy priority. These experiences also show the need to work across sectors and in continuous dialogue with all stakeholders, link bioeconomy initiatives with entrepreneurship and innovations in bio-based sectors, partner with international platforms and share knowledge with other countries and regions and improve coherence in the bioeconomy's sustainability objectives with climate and biodiversity and other multilateral agreements. The countries studied in this chapter tend to harness their natural resources and bioeconomies sustainably, albeit with different entry points aligned with their unique environmental challenges and economic structures. All of these countries illustrate a comprehensive and strategic pursuit of bioeconomy development, emphasizing sustainability, innovation, and cross-sectoral collaboration.

Potential of the bioeconomy for business in Africa: This featured article argues that countries with a vibrant bioeconomy would be likely to fully participate in and benefit from the Africa Continental Free Trade Area. Given its distributive nature, a bioeconomy will incentivize micro-, small-, and medium-size enterprises and the informal sector, which together make up a large part of the African economy. However, in order to fully exploit the business potential of a bioeconomy, African countries should develop bioeconomy clusters of innovation and entrepreneurial activities based on renewable biological resources and their unique needs and natural advantages.

Optimization of innovative climate financing mechanisms: The analysis presented in this chapter indicates that current climate finance flows to agrifood systems fall significantly short of meeting Africa's requirements. The adaptation finance gap is particularly large for small-scale agrifood systems. Moreover, current climate finance flows inadequately address gender inequality and social exclusion. Given the existing structural, institutional, and technical barriers currently constraining the effective mobilization and deployment of climate finance for agrifood systems, it is critically important to focus on the application of blended finance instruments and their potential to catalyze private investment at scale by de-risking agrifood transactions or creating more attractive risk-adjusted returns that also deliver environmental and social benefits.

A just energy transition: A review of the challenges and pathways for transitioning from fossil fuels and biomass energy to sustainable renewable energy in Africa indicates that this shift, a critical strategy for addressing climate change and ensuring sustainable development, is best achieved through a "just" transition. This would address not only the issue of sustainability but also that of accessing affordable energy options and creating job opportunities for the continent's marginalized populations. The chapter further stresses the importance of mini-grids and other decentralized energy solutions as vital technical pathways for achieving a just energy transition, particularly in remote and underserved regions.

Mainstreaming of the bioeconomy in the post-Malabo CAADP agenda: Africa, which has significantly lower carbon emissions than other regions, has a competitive advantage in developing a sustainable bioeconomy. This chapter explores the possibilities of mainstreaming the bioeconomy in Africa. The East African Community has set a good example by developing a dedicated regional bioeconomy strategy; other regional economic blocs should do the same. Ultimately, bringing together the regions' bioeconomy strategies would reflect a true African bioeconomy. The continent should harness opportunities for collaboration and partnerships globally to advance its bioeconomy, while considering its unique needs, values, and competitive advantages. In advancing the bioeconomy, Africa should always uphold its cross-sectoral nature, although agriculture remains the primary custodian of the bioeconomy, as it contributes to 30 percent of the continent's GDP.

Compliance with emerging environmental standards: A new trend is emerging as food supply chains move toward greater reporting of quantified environmental impacts, such as carbon footprints. This featured article focuses on the rise of environmental impact reporting in agrifood systems, particularly in European markets, and its implication for future African agricultural exports. The article highlights key risks associated with environmental standard compliance, including the possibility of creating fragmented landscapes due to different initiatives and requirements, which could lead to confusion and high transaction costs. It is likely that the trend will disproportionately affect producers in low- and middle-income countries due to a lack of adequate conformity assessments and verifications.

Limited progress in advancing CAADP implementation: This chapter, which tracks the progress made by African countries against CAADP indicators, indicates that out of the 49 member states of the African Union that participated in the fourth Biennial Review in 2023, not a single country is on track to achieve the Malabo commitments by 2025. This result implies that concerted efforts will be required to strengthen CAADP implementation capacities at the country and regional levels, including through embedding national agriculture investment plans in country planning and budgeting cycles and enhancing interministerial and intercountry coordination. More importantly, it is crucial to understand how countries can best achieve the commitments under the CAADP through an in-depth analysis of factors that contribute to this limited progress.

The analyses presented in this report generally indicate that Africa is at a crossroads, whereby emerging challenges and opportunities are together shaping its sustainable development progress and economic growth potential. The ATOR calls for a systematic and well-designed strategic approach to address challenges while also tapping into opportunities. More importantly, the continent must build capacities to translate strategic choices and agendas into actions. The ongoing negotiations over the next 10-year CAADP implementation agenda present an opportune moment for African leaders to consider the insights and recommendations presented in this edition of the ATOR, as well as to align with emerging initiatives such as the implementation of countries' United Nations Food Systems Summit national pathways, the revision of existing NDCs in 2025, and the hosting of the Global Bioeconomy Summit in October 2024, for the first time in Africa.

ANNEXES

Core CAADP Monitoring & Evaluation and Supplementary Indicators

Annexes:
Core CAADP Monitoring & Evaluation and Supplementary Indicators

This section presents data and trends across three levels of the CAADP Results Framework as well as supplementary data and trends.[1]

The data are presented at the aggregate level for the entire continent (Africa); the five geographic regions of the African Union (central, eastern, northern, southern, and western); eight regional economic communities (CEN-SAD, COMESA, EAC, ECCAS, ECOWAS, IGAD, SADC, and UMA);[2] five economic categories defined by agricultural production potential, nonagricultural sources of growth, and income level; nine CAADP groups representing either the period during which countries signed a CAADP compact or the level of CAADP implementation reached by countries by the end of 2015; and four levels of progress for countries in formulating national agriculture investment plans (NAIPs). Data for individual countries and regional groupings are available at www.resakss.org.

Technical Notes to Annex Tables

1. To control for year-to-year fluctuations, moving averages are used. Therefore, the values under the column "2003" are averages over the years 2002 to 2004 and the values under the column "2023" are averages over the years 2022 to 2023.
2. Annual average level and annual average change for 2014–2023 include data from 2014 up to either 2023 or the most recent prior year that is measured and available.
3. Annual average level is the simple average over the years shown, inclusive of the years shown.
4. Annual average change for all indicators is annual average percent change, from the beginning to the end years, shown by fitting an exponential growth function to the data points (that is, "LOGEST" function in Excel).
5. For indicators for which there are only a few measured data points over the years specified in the range (such as poverty, which is measured once every three to five years or so), a straight-line method was used to obtain missing values for the individual years between any two measured data points. Otherwise, estimated annual average change based on the measured values is used to obtain missing values either preceding or following the measured data point. In cases where the missing values could not be interpolated, the data are reported as missing and excluded from the calculations for that time period. Any weights used for these indicators are adjusted to account for the missing data in the series.

1 Future Annual Trends and Outlook Reports (ATORs) will report on more of the CAADP Results Framework indicators as more data become available.

2 CEN-SAD is the Community of Sahel-Saharan States; COMESA is the Common Market for Eastern and Southern Africa; EAC is the East African Community; ECCAS is the Economic Community of Central African States; ECOWAS is the Economic Community of West African States; IGAD is the Intergovernmental Authority on Development; SADC is the Southern African Development Community; and UMA is the Union du Maghreb Arabe (Arab Maghreb Union).

6. Values for Africa, the regional aggregations (central, eastern, northern, southern, and western), economic aggregations (less favorable agriculture conditions, more favorable agriculture conditions, mineral-rich countries, lower middle-income countries, and upper middle-income countries), regional economic communities (CEN-SAD, COMESA, EAC, ECCAS, ECOWAS, IGAD, SADC, and UMA), CAADP groups (Compact 2007–2009, Compact 2010–2012, Compact 2013–2015, Compact not yet, Level 0, Level 1, Level 2, Level 3, and Level 4), and NAIP groups (NAIP00, NAIP10, NAIP01, and NAIP11) are calculated by weighted summation. The weights vary by indicator and are based on each country's proportion in the total value of the indicator used for the weighting measured at the respective aggregate level. Each country i's weight in region j (w_{ij}) is then multiplied by the country's data point (x_i) and then summed for the relevant countries in the region to obtain the regional value (y_j) according to: $y_j = \Sigma_i w_{ij} x_i$.

The trend data are organized as follows:

Annex 1
Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development

Annex 2
Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth

Annex 3
Level 3— Strengthening Systemic Capacity to Deliver Results

Annex 4
Country Categories by Geographic Regions, Economic Classification, and Regional Economic Communities

Annex 5
Distribution of Countries by Year of Signing CAADP Compact and Level of CAADP Implementation Reached by End of 2015

Annex 6
Distribution of Countries in Formulating First-Generation Investment Plan (NAIP1.0) and Second-Generation Investment Plan (NAIP2.0) Reached by September of 2024

Annex 7
Supplementary Data Tables

ANNEX 1a: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.1.1

TABLE L1.1.1—GDP PER CAPITA (constant 2015 US$)										
Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014–2023)	Annual avg. change (%) (2014–2023)	2023
Africa	1,504.0	1.4	1,611.3	1,738.8	3.2	1,926.9	1.0	1,986.2	0.0	2,005.9
Central	713.1	–0.5	732.1	787.9	2.6	858.3	1.5	854.3	–0.9	841.9
Eastern	656.0	1.5	699.0	769.3	4.5	890.6	0.5	992.7	1.3	1,038.5
Northern	2,838.1	2.4	3,110.0	3,396.9	3.5	3,720.3	0.1	3,960.8	1.4	4,229.8
Southern	2,544.7	1.1	2,679.0	2,906.1	3.7	3,181.1	1.0	3,040.7	–1.7	2,879.6
Western	1,204.1	1.8	1,345.4	1,456.0	3.1	1,742.0	3.2	1,878.2	–0.2	1,887.7
Less favorable agriculture conditions	422.4	1.6	462.1	496.2	2.4	551.7	1.9	599.4	0.4	610.6
More favorable agriculture conditions	411.6	1.8	443.7	490.8	4.4	609.4	3.7	772.6	2.4	840.8
Mineral-rich countries	701.6	1.1	739.6	804.6	4.2	874.6	–2.7	798.2	–1.0	764.3
Lower middle-income countries	1,851.5	1.9	2,020.8	2,185.7	3.3	2,532.0	2.1	2,716.3	0.3	2,777.8
Upper middle-income countries	5,256.5	1.7	5,698.9	6,332.5	4.1	6,687.0	–0.3	6,430.4	–0.4	6,446.1
CEN-SAD	1,569.7	1.9	1,711.6	1,853.4	3.2	2,081.5	1.1	2,191.6	0.5	2,262.0
COMESA	1,205.6	1.2	1,250.5	1,342.9	3.2	1,452.0	0.0	1,558.3	1.8	1,716.8
EAC	597.0	–0.4	603.5	663.4	4.6	801.0	1.2	939.7	3.5	1,167.9
ECCAS	863.7	0.6	921.3	1,040.1	5.1	1,198.8	1.5	1,151.3	–1.9	1,092.1
ECOWAS	1,204.1	1.8	1,345.4	1,456.0	3.1	1,742.0	3.2	1,878.2	–0.2	1,887.7
IGAD	675.7	1.5	716.6	791.3	4.8	917.3	0.0	1,007.8	1.3	1,051.4
SADC	1,622.1	0.6	1,675.6	1,801.2	3.2	1,954.7	0.9	1,897.2	–1.4	1,818.5
UMA	3,249.8	2.3	3,596.3	3,959.3	3.3	4,177.8	–0.2	4,224.8	0.2	4,330.8
CAADP Compact 2007–09 (CC1)	949.0	2.0	1,082.0	1,191.2	3.8	1,469.9	3.6	1,612.3	0.0	1,629.3
CAADP Compact 2010–12 (CC2)	701.3	–0.1	702.4	744.4	2.6	846.8	2.6	999.8	1.7	1,069.7
CAADP Compact 2013–15 (CC3)	1,393.6	1.8	1,493.4	1,627.3	3.7	1,758.6	0.1	1,582.3	–2.9	1,423.0
CAADP Compact not yet (CC0)	3,160.6	2.0	3,430.6	3,726.8	3.2	3,983.4	0.1	4,121.8	0.8	4,323.0
CAADP Level 0 (CL0)	3,160.6	2.0	3,430.6	3,726.8	3.2	3,983.4	0.1	4,121.8	0.8	4,323.0
CAADP Level 1 (CL1)	1,461.4	1.8	1,562.4	1,713.1	4.1	1,861.0	0.1	1,637.5	–3.3	1,448.9
CAADP Level 2 (CL2)	591.3	–1.3	580.7	610.8	2.0	663.4	2.1	763.3	1.2	807.8
CAADP Level 3 (CL3)	535.1	1.9	575.1	609.4	2.7	711.0	2.5	780.4	0.7	807.5
CAADP Level 4 (CL4)	958.4	1.5	1,057.7	1,155.5	3.6	1,404.4	3.5	1,584.2	0.5	1,630.7
NAIP00 (N00)	3,476.8	1.7	3,792.0	4,163.3	3.8	4,545.3	0.7	4,365.0	–1.5	4,159.2
NAIP01 (N01)	2,373.5	2.1	2,553.9	2,781.3	3.6	3,025.6	–0.2	3,199.4	1.6	3,437.4
NAIP10 (N10)	443.2	–4.0	396.6	421.2	2.5	475.1	2.6	548.4	1.3	592.0
NAIP11 (N11)	941.1	1.5	1,023.1	1,103.8	3.2	1,298.4	2.4	1,414.1	0.3	1,439.5

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: GDP = gross domestic product. Aggregate value for a group is the sum of real GDP for countries in the group divided by total population of countries in the group.

ANNEX 1b: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.1.2

TABLE L1.1.2—HOUSEHOLD CONSUMPTION EXPENDITURE PER CAPITA (constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014–2023)	Annual avg. change (%) (2014–2023)	2023
Africa	1,103.9	0.1	1,100.7	1,139.3	2.1	1,214.3	−0.2	1,288.3	0.7	1,341.1
Central	463.4	−0.9	459.3	474.3	1.3	501.7	1.0	544.6	−0.9	515.4
Eastern	641.7	0.4	630.0	658.0	2.1	685.2	−1.1	732.8	1.2	769.0
Northern	1,745.1	0.3	1,757.6	1,795.5	2.0	2,147.2	2.8	2,595.7	1.8	2,758.0
Southern	2,020.4	−0.4	1,929.3	2,052.2	2.7	2,115.0	0.0	2,127.0	0.2	2,382.2
Western	548.9	1.0	572.6	622.1	4.3	707.0	0.9	874.8	3.5	1,014.9
Less favorable agriculture conditions	359.7	0.9	386.5	391.0	1.5	433.1	3.0	512.8	1.1	541.7
More favorable agriculture conditions	373.0	3.2	407.8	429.8	2.4	468.7	0.5	535.0	2.6	600.3
Mineral-rich countries	529.6	−2.1	473.4	501.9	2.5	574.9	1.9	568.0	−3.2	486.0
Lower middle-income countries	1,325.1	0.6	1,329.7	1,381.1	2.3	1,629.6	2.7	1,910.5	1.5	2,029.4
Upper middle-income countries	3,173.2	0.1	3,219.8	3,390.0	3.0	3,727.3	1.3	3,785.9	−0.9	3,688.9
CEN-SAD	1,135.6	0.6	1,142.0	1,186.1	2.7	1,382.2	1.9	1,559.5	1.6	1,684.4
COMESA	1,084.1	0.1	1,067.0	1,092.5	2.1	1,142.1	−1.7	1,211.7	1.7	1,328.8
EAC	463.5	0.8	467.6	491.9	2.3	556.2	2.6	655.1	2.8	800.7
ECCAS	464.5	0.9	517.7	527.8	1.2	604.9	2.3	685.9	−1.9	625.9
ECOWAS	548.9	1.0	572.6	622.1	4.3	707.0	0.9	874.8	3.5	1,014.9
IGAD	798.3	−0.5	758.0	789.7	2.0	758.4	−4.0	778.4	1.5	828.7
SADC	1,132.1	0.1	1,127.1	1,186.1	2.3	1,257.7	0.9	1,234.4	−1.4	1,202.9
UMA	1,692.7	−1.6	1,632.4	1,578.1	−0.2	1,769.2	2.4	2,089.4	0.3	2,074.2
CAADP Compact 2007–09 (CC1)	511.6	1.9	542.4	582.7	3.9	596.3	−3.3	656.0	4.0	791.7
CAADP Compact 2010–12 (CC2)	478.2	0.2	483.0	513.8	2.8	578.2	2.1	688.9	1.4	726.5
CAADP Compact 2013–15 (CC3)	859.2	−0.7	827.8	829.7	0.9	957.1	2.7	1,014.8	−3.1	868.0
CAADP Compact not yet (CC0)	2,042.9	0.6	2,088.5	2,190.5	2.7	2,505.1	1.5	2,762.0	1.0	2,875.6
CAADP Level 0 (CL0)	2,042.9	0.6	2,088.5	2,190.5	2.7	2,505.1	1.5	2,762.0	1.0	2,875.6
CAADP Level 1 (CL1)	894.9	−1.5	833.8	833.4	1.0	977.8	3.0	1,028.4	−3.8	846.7
CAADP Level 2 (CL2)	436.4	−0.5	431.8	464.6	3.1	497.5	0.6	542.9	−0.2	535.8
CAADP Level 3 (CL3)	381.8	1.2	403.4	427.1	2.6	501.3	2.6	537.9	0.6	571.0
CAADP Level 4 (CL4)	583.9	1.6	612.6	650.3	3.0	674.8	−1.4	791.5	3.4	907.4
NAIP00 (N00)	2,411.5	−1.2	2,228.4	2,322.0	1.8	2,453.9	0.1	2,438.2	−1.2	2,317.2
NAIP01 (N01)	1,547.9	0.7	1,578.8	1,630.9	2.7	1,968.5	2.8	2,322.2	1.7	2,475.6
NAIP10 (N10)	360.5	−2.8	326.5	347.2	1.8	367.4	0.5	388.7	−1.1	365.3
NAIP11 (N11)	612.0	0.6	617.0	647.0	2.6	690.6	−0.1	771.6	1.7	837.2

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: Aggregate value for a group is the sum of household consumption expenditure for countries in the group divided by total population of countries in the group.

ANNEX 1c: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.1

TABLE L1.2.1—PREVALENCE OF UNDERNOURISHMENT (% of population)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. level (2014-2022)	2022
Africa	21.7	19.8	−4.0	16.5	−2.0	17.8	3.0	20.0
Central	29.4	28.4	−1.9	25.1	−1.2	27.1	2.4	29.6
Eastern	36.0	32.0	−5.1	24.3	−4.8	24.4	3.4	27.1
Northern	5.5	5.4	−2.3	4.9	−0.7	5.5	3.9	6.5
Southern	25.5	23.8	−3.2	18.0	−3.0	20.0	0.8	20.8
Western	14.9	13.1	−5.0	12.3	1.5	13.5	3.3	15.7
Less favorable agriculture conditions	33.7	32.1	−2.3	27.6	−2.8	24.7	−0.1	25.3
More favorable agriculture conditions	32.2	28.2	−6.0	21.2	−2.5	23.7	2.4	25.1
Mineral-rich countries	33.8	33.2	−1.1	28.7	−4.5	25.8	1.5	27.3
Lower middle-income countries	14.5	13.0	−4.6	10.8	−1.8	12.2	4.9	14.9
Upper middle-income countries	4.9	5.1	2.1	6.5	4.9	8.2	3.3	9.6
CEN-SAD	15.6	14.2	−3.9	12.8	−0.7	13.8	3.5	16.1
COMESA	27.5	25.4	−3.6	21.0	−2.8	22.6	3.8	25.9
EAC	30.0	28.3	−2.2	25.7	−0.8	29.3	2.0	31.0
ECCAS	34.5	32.6	−2.6	25.3	−4.0	26.0	2.7	28.6
ECOWAS	14.9	13.1	−5.0	12.3	1.5	13.5	3.3	15.7
IGAD	37.5	32.9	−5.7	23.7	−6.2	23.2	4.2	26.5
SADC	28.5	26.8	−2.8	22.5	−1.7	24.9	1.8	26.6
UMA	5.6	5.3	−2.4	4.3	−5.3	4.0	4.4	4.9
CAADP Compact 2007-09 (CC1)	20.6	17.7	−6.7	14.0	−1.6	14.9	5.2	18.0
CAADP Compact 2010-12 (CC2)	30.6	28.5	−3.0	24.8	−1.1	27.3	1.3	28.7
CAADP Compact 2013-15 (CC3)	35.8	32.0	−4.7	20.6	−8.9	19.8	3.9	22.4
CAADP Compact not yet (CC0)	8.3	8.3	−0.2	8.3	−0.2	8.9	2.5	10.0
CAADP Level 0 (CL0)	8.3	8.3	−0.2	8.3	−0.2	8.9	2.5	10.0
CAADP Level 1 (CL1)	39.6	36.0	−4.1	24.0	−9.2	22.3	3.9	25.3
CAADP Level 2 (CL2)	26.8	26.0	−1.6	23.2	−1.1	24.9	2.0	26.8
CAADP Level 3 (CL3)	26.4	24.7	−2.6	21.7	−0.6	24.3	1.2	25.4
CAADP Level 4 (CL4)	24.3	21.0	−6.1	16.7	−1.8	18.0	3.5	20.6
NAIP00 (N00)	19.7	18.8	−1.8	14.1	−6.7	13.0	2.3	14.5
NAIP01 (N01)	11.0	10.6	−2.7	9.6	0.3	12.0	4.6	14.2
NAIP10 (N10)	31.3	31.2	−0.5	29.8	0.0	32.5	2.1	35.3
NAIP11 (N11)	24.4	21.5	−5.3	17.3	−2.2	18.5	2.9	20.5

Source: ReSAKSS based on FAO (2024), World Bank (2024), and ILO (2024).
Note: Data are only available from 2000 to 2022.

ANNEX 1d: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2A

TABLE L1.2.2A—PREVALENCE OF UNDERWEIGHT, WEIGHT FOR AGE (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	23.7	–1.2	22.4	21.5	–1.5	19.4	–2.1	17.1	–1.9	16.1
Central	27.1	–1.0	25.9	25.0	–1.5	23.1	–1.3	20.9	–2.0	19.4
Eastern	27.7	–1.4	25.7	24.8	–1.6	22.3	–2.0	19.7	–1.7	18.4
Northern	8.7	–1.8	8.2	7.0	–4.5	6.2	–1.5	5.1	–3.8	4.5
Southern	18.1	–1.2	17.1	15.8	–3.1	13.7	–2.4	11.1	–3.8	9.7
Western	27.3	–1.7	25.5	24.8	–1.0	22.5	–2.4	20.1	–1.7	19.0
Less favorable agriculture conditions	31.8	–1.3	30.3	29.8	–1.3	27.4	–0.3	25.8	–1.6	24.7
More favorable agriculture conditions	29.2	–2.0	26.3	24.8	–2.5	21.5	–2.8	17.2	–3.1	15.4
Mineral-rich countries	25.4	–0.1	25.1	24.6	–0.8	23.9	–0.5	23.1	–0.5	22.6
Lower middle-income countries	19.9	–1.3	18.9	18.1	–1.3	16.2	–3.0	14.1	–2.1	13.0
Upper middle-income countries	9.2	–1.4	8.6	8.4	0.5	7.7	–3.5	6.4	–1.9	6.0
CEN-SAD	22.5	–0.9	21.7	21.3	–0.7	19.8	–1.7	18.5	–1.0	17.9
COMESA	24.2	–1.0	23.0	22.1	–1.6	20.2	–1.5	18.0	–1.6	17.0
EAC	23.7	–1.9	21.5	20.7	–1.6	18.3	–2.6	15.4	–4.1	12.7
ECCAS	27.2	–1.6	25.4	24.1	–2.4	21.8	–1.9	18.9	–2.8	17.0
ECOWAS	27.3	–1.7	25.5	24.8	–1.0	22.5	–2.4	20.1	–1.7	19.0
IGAD	28.4	–1.3	26.6	25.9	–1.4	23.6	–1.7	21.2	–1.3	20.2
SADC	23.1	–1.2	21.6	20.4	–2.2	18.1	–2.2	15.6	–2.5	14.1
UMA	8.3	–0.8	8.2	6.7	–6.2	5.5	–3.1	4.2	–5.1	3.5
CAADP Compact 2007–09 (CC1)	31.6	–1.9	29.0	27.8	–1.8	24.6	–2.6	21.4	–2.3	19.8
CAADP Compact 2010–12 (CC2)	22.7	–1.6	20.9	20.1	–1.4	17.9	–2.3	15.4	–2.2	14.3
CAADP Compact 2013–15 (CC3)	22.7	–1.6	20.9	20.1	–1.4	17.9	–2.3	15.4	–2.2	14.3
CAADP Compact not yet (CC0)	10.2	–0.8	10.0	9.4	–1.6	8.5	–1.5	7.7	–1.1	7.5
CAADP Level 0 (CL0)	10.2	–0.8	10.0	9.4	–1.6	8.5	–1.5	7.7	–1.1	7.5
CAADP Level 1 (CL1)	25.3	–0.2	25.3	24.6	–1.5	24.0	–0.7	22.7	–1.2	21.6
CAADP Level 2 (CL2)	25.6	–0.9	24.3	23.5	–1.6	21.9	–1.2	19.9	–1.6	18.8
CAADP Level 3 (CL3)	25.7	–1.6	23.9	23.0	–1.8	20.8	–1.4	18.2	–2.0	17.4
CAADP Level 4 (CL4)	27.8	–2.0	25.3	24.3	–1.6	21.3	–3.0	18.1	–2.5	16.5
NAIP00 (N00)	15.7	–0.5	15.5	14.3	–2.7	12.4	–3.1	10.3	–3.1	9.3
NAIP01 (N01)	15.1	–0.4	15.1	14.2	–2.5	13.1	–1.4	11.4	–2.2	10.5
NAIP10 (N10)	28.9	–1.0	27.3	26.3	–1.6	24.1	–1.6	21.7	–1.8	20.3
NAIP11 (N11)	26.2	–1.6	24.3	23.5	–1.4	21.1	–2.2	18.7	–1.8	17.6

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1e: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2B

TABLE L1.2.2B—PREVALENCE OF STUNTING, HEIGHT FOR AGE (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	41.1	−1.1	39.3	38.2	−1.1	35.0	−2.0	31.5	−1.5	29.7
Central	44.9	−1.0	43.8	43.2	−0.7	41.2	−0.8	39.0	−0.9	37.9
Eastern	47.6	−1.4	44.7	43.2	−1.6	38.9	−2.1	33.8	−2.1	31.1
Northern	25.4	−3.0	23.2	22.6	2.2	20.7	−3.5	17.2	−2.9	15.5
Southern	42.5	−0.9	40.9	38.8	−2.2	35.6	−2.0	30.8	−2.3	28.5
Western	39.3	−0.8	37.9	37.1	−1.1	34.1	−1.9	31.6	−1.1	30.2
Less favorable agriculture conditions	43.2	−0.4	41.9	42.2	−0.5	39.6	−0.7	37.6	−0.9	36.4
More favorable agriculture conditions	50.4	−1.6	47.1	44.8	−1.9	40.5	−2.3	34.2	−2.3	31.4
Mineral-rich countries	43.9	−0.8	42.8	42.3	−0.6	40.2	−0.7	38.2	−0.9	37.1
Lower middle-income countries	35.5	−1.2	33.9	33.1	−0.8	30.0	−2.7	26.7	−1.7	25.0
Upper middle-income countries	28.4	−0.9	27.3	26.6	−1.3	25.5	−0.6	23.8	−1.1	22.8
CEN-SAD	36.4	−1.0	35.0	34.6	−0.4	31.9	−2.0	29.4	−1.3	27.9
COMESA	44.1	−1.4	41.8	40.8	−0.6	37.6	−1.9	33.3	−1.6	31.6
EAC	45.3	−1.2	43.1	42.1	−1.1	39.0	−1.8	34.6	−2.5	30.9
ECCAS	46.3	−1.3	44.5	43.1	−1.5	40.5	−1.3	37.0	−1.6	35.2
ECOWAS	39.3	−0.8	37.9	37.1	−1.1	34.1	−1.9	31.6	−1.1	30.2
IGAD	47.1	−1.5	44.0	42.5	−1.6	37.9	−2.0	32.8	−2.3	30.1
SADC	45.5	−1.0	43.8	42.1	−1.6	39.1	−1.7	35.1	−1.6	33.1
UMA	22.9	−1.3	21.6	19.6	−2.8	17.2	−2.3	14.5	−3.0	13.1
CAADP Compact 2007–09 (CC1)	46.3	−1.1	43.9	42.4	−1.6	38.4	−2.2	34.7	−1.5	32.7
CAADP Compact 2010–12 (CC2)	43.2	−1.3	41.1	40.0	−1.1	36.9	−1.8	32.9	−1.6	30.9
CAADP Compact 2013–15 (CC3)	43.2	−1.3	41.1	40.0	−1.1	36.9	−1.8	32.9	−1.6	30.9
CAADP Compact not yet (CC0)	26.9	−2.1	25.0	24.7	1.3	22.8	−2.5	19.9	−1.9	18.7
CAADP Level 0 (CL0)	26.9	−2.1	25.0	24.7	1.3	22.8	−2.5	19.9	−1.9	18.7
CAADP Level 1 (CL1)	43.3	−1.2	41.6	40.0	−2.0	37.3	−1.5	33.5	−2.0	31.3
CAADP Level 2 (CL2)	43.2	−1.0	42.1	41.7	−0.7	39.6	−0.7	37.6	−0.8	36.6
CAADP Level 3 (CL3)	43.9	−1.0	41.4	40.6	−1.1	37.7	−1.3	34.1	−1.5	32.5
CAADP Level 4 (CL4)	45.1	−1.3	42.7	41.1	−1.6	37.0	−2.4	32.7	−1.8	30.4
NAIP00 (N00)	32.6	−0.8	31.5	29.5	−2.7	26.4	−2.0	22.9	−2.7	21.0
NAIP01 (N01)	32.4	−2.2	30.5	30.2	1.4	28.4	−2.7	24.5	−2.0	22.9
NAIP10 (N10)	47.2	−1.1	45.9	45.2	−0.6	43.0	−0.8	40.7	−0.9	39.4
NAIP11 (N11)	43.6	−1.1	41.4	40.2	−1.4	36.7	−2.0	32.9	−1.6	31.0

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: Data only available up to 2022. For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1f: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2C

TABLE L1.2.2C—PREVALENCE OF WASTING, WEIGHT FOR HEIGHT (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	9.7	–1.2	9.1	8.8	–1.3	8.0	–2.0	7.0	–1.8	6.7
Central	11.3	–0.5	10.3	9.9	–2.3	8.4	–2.7	6.8	–3.8	5.8
Eastern	9.4	–1.0	8.9	8.9	–1.2	8.2	–1.5	7.5	–1.3	7.3
Northern	6.0	0.5	6.4	6.1	0.9	6.7	1.8	7.4	0.8	7.7
Southern	6.2	–1.9	5.7	5.5	–1.0	4.8	–1.5	4.0	–1.9	3.7
Western	12.4	–2.4	11.3	10.8	–1.6	9.5	–3.2	7.8	–2.4	7.2
Less favorable agriculture conditions	14.9	–2.7	13.6	12.6	–3.3	11.3	–1.2	9.5	–3.8	8.3
More favorable agriculture conditions	9.0	–1.9	8.3	8.0	–2.4	7.0	–2.1	6.0	–2.1	5.8
Mineral-rich countries	11.7	0.1	11.0	10.7	–1.5	9.8	–1.4	8.7	–1.6	8.2
Lower middle-income countries	9.1	–1.3	8.6	8.4	–0.3	7.7	–2.5	6.9	–1.4	6.5
Upper middle-income countries	4.6	–0.3	4.5	4.7	3.1	4.5	–3.2	4.0	0.0	4.0
CEN-SAD	10.9	–1.3	10.4	10.1	–0.8	9.4	–1.9	8.5	–1.4	8.1
COMESA	9.2	–0.4	8.8	8.7	–0.6	8.2	–1.1	7.7	–1.0	7.5
EAC	8.4	–1.4	7.4	7.2	–1.3	6.2	–2.9	4.9	–4.6	4.1
ECCAS	10.5	–0.8	9.6	9.2	–2.1	7.8	–2.7	6.3	–3.6	5.4
ECOWAS	12.4	–2.4	11.3	10.8	–1.6	9.5	–3.2	7.8	–2.4	7.2
IGAD	10.0	–0.6	9.7	9.7	–0.7	9.2	–1.4	8.8	–0.7	8.6
SADC	8.2	–1.0	7.6	7.2	–2.0	6.1	–2.1	4.9	–3.3	4.4
UMA	6.0	1.3	6.6	5.5	–7.3	4.8	–0.7	4.3	–1.8	4.3
CAADP Compact 2007–09 (CC1)	12.1	–2.2	11.0	10.6	–2.0	9.3	–2.8	7.8	–2.6	7.2
CAADP Compact 2010–12 (CC2)	8.8	–1.5	7.9	7.7	–1.2	6.7	–2.5	5.6	–2.5	5.1
CAADP Compact 2013–15 (CC3)	8.8	–1.5	7.9	7.7	–1.2	6.7	–2.5	5.6	–2.5	5.1
CAADP Compact not yet (CC0)	6.6	0.3	6.8	6.6	0.6	6.7	–0.2	6.7	–0.1	6.7
CAADP Level 0 (CL0)	6.6	0.3	6.8	6.6	0.6	6.7	–0.2	6.7	–0.1	6.7
CAADP Level 1 (CL1)	10.2	0.1	10.5	10.4	–1.0	9.9	–0.4	9.7	–0.5	9.4
CAADP Level 2 (CL2)	11.4	–0.5	10.3	9.8	–2.7	8.3	–2.7	6.6	–3.7	5.8
CAADP Level 3 (CL3)	9.5	–2.2	8.8	8.5	–2.2	7.7	0.0	7.0	–2.0	6.8
CAADP Level 4 (CL4)	10.5	–2.2	9.4	9.2	–1.3	8.0	–3.4	6.6	–2.4	6.1
NAIP00 (N00)	7.5	–0.7	7.4	6.8	–0.9	5.9	–3.8	4.7	–2.7	4.2
NAIP01 (N01)	7.4	0.9	8.1	7.9	–0.2	8.2	0.7	8.6	0.0	8.5
NAIP10 (N10)	12.5	–0.2	11.2	10.5	–2.6	8.6	–3.3	6.5	–4.5	5.5
NAIP11 (N11)	10.2	–1.9	9.4	9.1	–1.3	8.2	–2.1	7.2	–1.8	6.8

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: Data only available up to 2022. For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1g: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.3

TABLE L1.2.3—CEREAL IMPORT DEPENDENCY RATIO (%)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014–2021)	Annual avg. change (%) (2014–2021)	2021
Africa	25.1	25.5	1.2	28.8	2.3	30.1	−0.2	30.0
Central	30.7	30.0	−0.7	28.4	−2.6	25.6	0.8	25.9
Eastern	13.2	13.7	2.6	18.0	2.8	20.8	0.9	20.4
Northern	43.7	45.6	3.8	52.3	1.5	58.5	1.1	59.8
Southern	24.9	25.9	−0.4	26.8	3.8	29.0	−4.1	27.7
Western	22.6	22.5	−0.7	25.8	4.2	24.8	−0.2	24.8
Less favorable agriculture conditions	10.3	10.8	0.8	20.3	22.0	27.8	1.1	28.2
More favorable agriculture conditions	13.4	13.4	−1.3	13.0	1.3	15.3	0.6	15.1
Mineral-rich countries	23.2	19.9	−7.4	17.2	4.9	20.6	3.2	22.4
Lower middle-income countries	33.7	34.6	2.1	40.5	2.0	40.5	−0.2	40.5
Upper middle-income countries	16.9	19.1	3.2	23.6	10.3	31.0	−5.5	28.0
CEN-SAD	25.8	26.8	2.6	33.3	4.1	35.4	0.2	35.5
COMESA	20.3	20.9	3.4	26.5	2.2	29.3	0.4	29.3
EAC	13.6	16.3	6.2	21.0	0.7	21.6	0.4	20.9
ECCAS	37.6	37.8	−0.2	34.5	−3.7	29.4	−0.1	29.2
ECOWAS	22.6	22.5	−0.7	25.8	4.2	24.8	−0.2	24.8
IGAD	13.4	13.6	3.6	20.2	3.7	24.0	1.8	24.1
SADC	21.0	21.8	−0.6	21.8	2.6	22.5	−3.0	21.5
UMA	58.0	58.7	2.2	61.3	0.5	70.1	2.3	73.4
CAADP Compact 2007–09 (CC1)	17.0	16.5	−1.1	19.4	4.1	19.5	0.1	19.6
CAADP Compact 2010–12 (CC2)	22.3	22.9	0.3	24.2	0.1	24.4	0.4	24.3
CAADP Compact 2013–15 (CC3)	22.3	22.9	0.3	24.2	0.1	24.4	0.4	24.3
CAADP Compact not yet (CC0)	35.6	37.6	3.8	44.6	3.4	52.0	0.0	52.1
CAADP Level 0 (CL0)	35.6	37.6	3.8	44.6	3.4	52.0	0.0	52.1
CAADP Level 1 (CL1)	35.8	37.0	1.3	40.9	1.5	37.3	−2.0	36.6
CAADP Level 2 (CL2)	32.2	30.9	−0.8	28.4	−3.5	26.5	1.1	27.1
CAADP Level 3 (CL3)	15.1	14.7	−5.5	11.4	1.6	13.6	9.9	16.8
CAADP Level 4 (CL4)	19.2	19.3	0.4	23.0	2.9	23.0	−1.1	22.2
NAIP00 (N00)	39.7	41.0	1.1	44.8	3.4	48.1	−1.8	46.6
NAIP01 (N01)	32.0	33.9	4.9	40.9	2.7	46.8	1.0	47.8
NAIP10 (N10)	28.7	29.1	1.2	27.2	−7.0	22.5	0.9	22.7
NAIP11 (N11)	20.0	20.1	−0.2	22.7	2.5	23.0	−0.1	23.0

Source: ReSAKSS based on FAO (2024), World Bank (2024), and ILO (2024).

Note: Data are only available from 2000 to 2021. For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1h: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.1A

TABLE L1.3.1A—EMPLOYMENT RATE (% of labor force, 15-64 years)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	90.0	0.0	90.1	90.8	0.3	91.1	−0.1	90.7	−0.1	90.6
Central	92.9	−0.2	92.7	93.5	0.3	93.3	−0.2	92.3	−0.1	92.2
Eastern	91.7	0.0	91.8	92.3	0.2	92.5	0.0	92.1	−0.2	91.6
Northern	83.5	0.1	83.5	85.8	1.2	87.5	−0.2	88.0	0.1	88.7
Southern	84.7	0.1	84.9	85.3	0.3	84.8	−0.5	83.4	−0.2	82.8
Western	93.3	0.0	93.5	93.5	0.0	93.9	0.1	93.5	−0.1	93.7
Less favorable agriculture conditions	92.4	0.0	92.2	92.3	0.1	93.1	0.2	92.6	−0.3	91.7
More favorable agriculture conditions	93.7	0.0	93.7	94.3	0.2	94.4	0.0	93.9	−0.1	93.7
Mineral-rich countries	90.7	−0.2	90.3	90.6	0.1	90.1	−0.3	89.5	−0.1	89.5
Lower middle-income countries	88.9	0.1	89.2	90.1	0.4	90.8	0.0	90.6	0.0	91.0
Upper middle-income countries	78.8	0.0	79.0	79.7	0.5	78.4	−1.2	75.0	−0.7	72.0
CEN-SAD	91.1	0.0	90.8	91.2	0.2	91.6	0.0	91.4	−0.1	91.7
COMESA	91.0	−0.1	90.6	91.2	0.3	91.3	−0.1	91.7	0.2	94.1
EAC	93.4	−0.1	93.1	93.5	0.1	93.3	−0.1	92.7	−0.2	92.3
ECCAS	90.5	−0.1	90.4	91.0	0.2	90.7	−0.2	89.9	−0.1	90.0
ECOWAS	93.3	0.0	93.5	93.5	0.0	93.9	0.1	93.5	−0.1	93.7
IGAD	91.5	−0.1	91.5	91.9	0.1	91.9	0.0	91.4	−0.2	91.0
SADC	89.0	0.0	89.1	89.7	0.3	89.4	−0.3	88.6	−0.1	88.2
UMA	79.1	0.5	81.9	85.1	1.3	87.9	0.1	86.6	−0.4	85.8
CAADP Compact 2007–09 (CC1)	93.1	0.0	93.4	93.7	0.1	94.1	0.1	93.5	−0.1	93.5
CAADP Compact 2010–12 (CC2)	93.5	−0.1	93.2	93.5	0.2	93.4	−0.1	92.9	−0.1	92.8
CAADP Compact 2013–15 (CC3)	87.4	0.1	88.0	88.6	0.2	88.5	−0.1	87.8	−0.1	87.9
CAADP Compact not yet (CC0)	82.1	0.1	82.1	83.9	1.0	84.7	−0.4	84.0	−0.2	83.4
CAADP Level 0 (CL0)	82.1	0.1	82.1	83.9	1.0	84.7	−0.4	84.0	−0.2	83.4
CAADP Level 1 (CL1)	86.8	0.1	87.2	87.4	0.0	87.2	0.0	86.7	−0.1	86.8
CAADP Level 2 (CL2)	93.0	−0.1	93.1	93.9	0.3	93.5	−0.3	92.3	−0.1	92.2
CAADP Level 3 (CL3)	93.3	−0.1	92.9	93.1	0.2	93.9	0.2	93.8	0.0	94.0
CAADP Level 4 (CL4)	93.2	0.0	93.4	93.7	0.1	93.9	0.0	93.3	−0.1	93.2
NAIP00 (N00)	77.2	0.2	78.7	80.7	0.9	81.1	−0.6	79.0	−0.4	77.7
NAIP01 (N01)	88.0	0.0	87.1	88.2	0.7	89.1	−0.1	90.1	0.1	90.9
NAIP10 (N10)	94.1	−0.3	93.6	94.1	0.2	93.2	−0.4	92.0	−0.1	92.0
NAIP11 (N11)	92.5	0.0	92.6	92.9	0.1	93.1	0.0	92.6	−0.1	92.5

Source: ReSAKSS based on ILO (2024).
Note: For regions or groups, level is weighted average, where weight is country's share in total labor force for the region or group.

ANNEX 1i: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.1B

TABLE L1.3.1B—EMPLOYMENT RATE (% of population, 15+ years)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	59.7	−0.1	59.6	60.0	0.2	59.5	−0.3	58.3	−0.2	58.5
Central	70.4	−0.1	70.3	69.7	−0.6	65.9	−1.0	63.9	−0.2	63.9
Eastern	69.1	0.1	69.7	70.1	0.1	69.9	−0.1	68.7	−0.4	68.2
Northern	40.0	−0.6	39.3	40.9	1.6	41.8	−0.6	39.4	−0.4	39.7
Southern	59.3	−0.2	58.8	58.7	0.0	56.7	−0.5	56.1	−0.1	56.2
Western	61.8	−0.1	61.6	61.4	−0.1	60.7	−0.3	59.1	−0.2	59.3
Less favorable agriculture conditions	64.1	−0.4	63.2	62.9	−0.1	62.8	−0.3	60.7	−0.4	60.1
More favorable agriculture conditions	76.8	0.1	77.3	77.5	0.0	76.4	−0.3	74.5	−0.3	74.0
Mineral-rich countries	60.6	−0.1	60.4	59.9	−0.5	57.3	−0.8	55.7	−0.2	55.6
Lower middle-income countries	53.0	−0.2	52.8	53.6	0.5	53.8	−0.2	52.6	−0.1	53.1
Upper middle-income countries	47.9	−0.3	47.3	47.2	−0.1	44.3	−0.9	42.9	−0.9	41.7
CEN-SAD	54.9	−0.3	54.3	54.7	0.3	54.6	−0.4	53.0	−0.2	53.1
COMESA	60.0	−0.1	59.8	60.4	0.4	60.4	−0.2	60.1	0.3	62.7
EAC	72.2	0.0	72.3	72.2	−0.2	70.3	−0.4	69.3	0.1	71.0
ECCAS	68.5	−0.1	68.3	67.8	−0.4	64.8	−0.8	63.0	−0.1	63.1
ECOWAS	61.8	−0.1	61.6	61.4	−0.1	60.7	−0.3	59.1	−0.2	59.3
IGAD	65.6	0.1	66.2	66.6	0.2	66.7	0.0	65.8	−0.3	65.3
SADC	66.7	0.0	66.7	66.7	−0.1	64.5	−0.5	63.5	−0.1	63.6
UMA	38.4	0.0	39.0	40.1	1.0	40.5	−0.3	38.6	−0.7	38.3
CAADP Compact 2007–09 (CC1)	65.6	0.1	66.0	66.2	0.1	66.2	−0.2	64.6	−0.2	64.7
CAADP Compact 2010–12 (CC2)	70.0	−0.1	69.8	69.5	−0.3	67.5	−0.5	66.1	−0.2	66.0
CAADP Compact 2013–15 (CC3)	62.5	−0.1	62.5	62.6	0.0	61.5	−0.4	60.1	−0.3	59.9
CAADP Compact not yet (CC0)	42.6	−0.5	41.9	43.0	1.1	43.0	−0.6	40.8	−0.6	40.6
CAADP Level 0 (CL0)	42.6	−0.5	41.9	43.0	1.1	43.0	−0.6	40.8	−0.6	40.6
CAADP Level 1 (CL1)	60.0	−0.1	59.8	59.8	−0.1	59.4	−0.1	58.3	−0.3	58.2
CAADP Level 2 (CL2)	68.3	0.1	68.6	68.1	−0.6	63.9	−1.2	61.5	−0.2	61.4
CAADP Level 3 (CL3)	67.1	−0.1	66.9	67.0	0.2	67.1	−0.2	66.0	−0.1	66.0
CAADP Level 4 (CL4)	68.0	0.0	68.2	68.3	0.0	67.7	−0.2	66.3	−0.2	66.2
NAIP00 (N00)	44.7	−0.2	44.7	45.4	0.5	44.4	−0.4	43.6	−0.4	43.4
NAIP01 (N01)	47.8	−0.5	46.8	48.2	1.2	49.0	−0.4	47.1	−0.2	47.6
NAIP10 (N10)	69.2	0.0	69.3	68.5	−0.8	64.2	−1.0	62.5	−0.1	62.6
NAIP11 (N11)	66.2	0.0	66.3	66.4	0.0	65.7	−0.3	64.2	−0.2	64.1

Source: ReSAKSS based on ILO (2024).

Note: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1j: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.3

TABLE L1.3.3—POVERTY GAP AT $2.15/ DAY (2017 PPP) (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2021)	Annual avg. change (%) (2014-2021)	2021
Africa	18.3	−2.8	16.1	14.9	−3.2	12.2	−3.7	10.8	−0.7	10.5
Central	23.1	−2.9	21.0	19.4	−3.6	16.6	−2.6	13.3	−3.6	12.0
Eastern	22.3	−2.6	18.9	17.7	−2.2	14.6	−3.7	15.8	2.1	15.8
Northern	0.9	−4.2	0.8	0.6	−5.8	0.4	−10.9	0.2	−6.1	0.2
Southern	19.4	−1.0	18.5	17.8	−3.3	16.2	−0.5	15.9	0.3	15.8
Western	22.4	−3.9	19.2	17.4	−4.2	12.8	−5.9	8.9	−5.6	7.5
Less favorable agriculture conditions	33.8	−3.4	29.5	27.0	−4.2	20.0	−5.7	14.5	−2.6	13.8
More favorable agriculture conditions	27.5	−2.9	23.4	21.7	−2.3	18.1	−3.9	19.9	3.7	20.8
Mineral-rich countries	29.9	−2.7	26.6	25.6	−3.6	20.6	−3.7	22.6	10.4	31.0
Lower middle-income countries	11.1	−2.8	10.1	9.4	−3.7	7.6	−3.1	6.6	−2.0	6.2
Upper middle-income countries	11.4	−3.0	9.5	8.3	−8.9	6.1	0.7	4.1	−11.2	2.8
CEN-SAD	15.4	−3.4	13.5	12.4	−3.8	9.5	−5.1	7.1	−4.0	6.3
COMESA	14.8	−1.9	13.2	12.8	−0.9	11.4	−2.6	12.7	2.6	13.2
EAC	23.6	−1.6	21.1	19.5	−3.1	16.0	−3.1	13.2	−3.7	11.6
ECCAS	20.3	−2.4	18.5	17.1	−4.1	14.8	−1.6	12.6	−3.0	11.5
ECOWAS	22.4	−3.9	19.2	17.4	−4.2	12.8	−5.9	8.9	−5.6	7.5
IGAD	17.8	−3.9	14.1	13.0	−2.4	9.7	−6.1	10.5	2.8	10.4
SADC	23.0	−0.7	21.7	20.9	−2.4	19.2	−1.0	18.3	−0.4	17.9
UMA	1.9	−4.8	1.4	1.2	−8.4	0.7	−13.7	0.4		0.1
CAADP Compact 2007–09 (CC1)	22.6	−4.2	18.7	16.9	−4.2	12.4	−6.0	9.9	−3.0	8.8
CAADP Compact 2010–12 (CC2)	24.4	−2.0	22.0	20.8	−2.5	17.6	−3.1	15.3	−0.9	14.9
CAADP Compact 2013–15 (CC3)	24.4	−2.0	22.0	20.8	−2.5	17.6	−3.1	15.3	−0.9	14.9
CAADP Compact not yet (CC0)	4.2	−3.5	3.5	3.0	−8.6	2.1	−1.1	1.5	−8.4	1.1
CAADP Level 0 (CL0)	4.2	−3.5	3.5	3.0	−8.6	2.1	−1.1	1.5	−8.4	1.1
CAADP Level 1 (CL1)	20.9	0.7	21.4	20.9	−0.8	20.0	−1.4	20.4	1.5	21.3
CAADP Level 2 (CL2)	19.4	−4.3	16.7	15.0	−5.4	11.3	−5.2	8.8	1.2	9.8
CAADP Level 3 (CL3)	30.6	−2.7	27.4	25.4	−3.4	19.7	−4.4	16.4	−0.4	16.4
CAADP Level 4 (CL4)	21.6	−3.4	18.3	16.9	−3.4	13.3	−4.6	11.5	−2.0	10.5
NAIP00 (N00)	11.0	−2.0	9.7	8.5	−8.3	7.2	3.3	6.5	−3.7	5.8
NAIP01 (N01)	6.1	1.1	6.3	6.4	1.1	6.7	0.7	8.0	4.6	9.2
NAIP10 (N10)	42.8	−2.5	38.9	35.3	−5.6	29.8	−1.2	27.0	0.1	27.1
NAIP11 (N11)	22.8	−3.3	19.5	18.1	−3.4	14.1	−4.8	12.1	−1.2	11.4

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: Data only available up to 2021. For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1k: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.4

TABLE L1.3.4—POVERTY HEADCOUNT RATIO AT $2.15/ DAY (2017 PPP, % of population)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2021)	Annual avg. change (%) (2014-2021)	2021
Africa	44.0	–1.8	40.6	38.6	–2.2	33.9	–2.3	30.8	–1.0	30.0
Central	54.5	–2.2	51.2	48.8	–2.3	43.6	–1.9	38.0	–2.0	36.1
Eastern	56.5	–1.9	50.4	48.1	–1.7	42.1	–2.5	44.9	2.0	45.7
Northern	4.6	–4.0	4.0	3.5	–4.5	2.2	–10.5	1.2	–8.1	0.8
Southern	43.7	–0.5	42.6	41.1	–2.2	38.7	–0.1	38.8	0.4	38.9
Western	52.1	–2.4	47.6	44.6	–2.7	37.5	–3.4	30.4	–3.2	28.1
Less favorable agriculture conditions	71.8	–2.1	65.9	62.6	–2.4	53.0	–3.3	44.9	–0.8	46.5
More favorable agriculture conditions	65.2	–2.1	58.1	55.0	–1.8	47.9	–2.8	50.1	1.8	50.7
Mineral-rich countries	58.4	–0.7	57.1	54.8	–2.2	47.9	–2.2	49.1	5.8	64.3
Lower middle-income countries	29.2	–1.6	27.7	26.4	–2.2	23.6	–1.7	21.6	–1.4	20.7
Upper middle-income countries	31.6	–2.6	27.4	24.8	–6.5	19.4	–0.4	14.5	–7.3	11.5
CEN-SAD	36.7	–1.9	34.2	32.5	–2.3	28.0	–2.9	23.5	–2.8	21.7
COMESA	38.8	–1.4	35.6	34.7	–0.9	31.5	–1.9	32.3	1.5	33.3
EAC	56.3	–0.9	53.1	51.0	–1.6	46.0	–1.5	42.5	–1.4	40.5
ECCAS	46.9	–1.5	44.5	42.5	–2.4	39.2	–0.8	36.2	–1.3	34.9
ECOWAS	52.1	–2.4	47.6	44.6	–2.7	37.5	–3.4	30.4	–3.2	28.1
IGAD	50.2	–2.6	43.1	40.6	–2.0	33.6	–3.6	35.8	2.8	37.1
SADC	51.6	–0.5	49.9	48.5	–1.6	45.6	–0.6	44.7	–0.1	44.3
UMA	7.8	–4.8	6.1	5.1	–7.3	3.0	–13.1	0.8	–25.6	0.6
CAADP Compact 2007–09 (CC1)	55.3	–2.7	48.8	45.7	–3.0	37.7	–3.7	33.3	–1.1	32.2
CAADP Compact 2010–12 (CC2)	55.0	–1.1	52.2	50.1	–1.1	45.8	–1.8	42.4	–1.0	41.3
CAADP Compact 2013–15 (CC3)	43.7	–0.4	44.0	43.2	–1.0	41.4	–0.8	42.1	–0.8	43.1
CAADP Compact not yet (CC0)	13.1	–3.2	11.2	9.9	–6.2	7.3	–2.8	5.2	–7.6	4.0
CAADP Level 0 (CL0)	13.1	–3.2	11.2	9.9	–6.2	7.3	–2.8	5.2	–7.6	4.0
CAADP Level 1 (CL1)	46.2	0.6	47.3	46.8	–0.7	45.3	–0.8	47.2	1.3	48.9
CAADP Level 2 (CL2)	45.5	–3.1	41.4	38.3	–2.9	31.6	–3.6	27.3	0.3	28.8
CAADP Level 3 (CL3)	67.0	–1.5	63.0	59.5	–2.2	51.2	–2.8	45.8	–0.2	47.2
CAADP Level 4 (CL4)	52.8	–2.2	47.6	45.0	–2.2	38.9	–2.8	35.6	–1.0	34.1
NAIP00 (N00)	29.5	–1.8	26.5	24.4	–5.7	21.4	1.8	19.9	–2.4	18.5
NAIP01 (N01)	15.4	0.0	15.6	15.6	0.1	15.3	–0.5	15.5	0.4	15.6
NAIP10 (N10)	71.6	–1.2	68.4	65.3	–2.6	60.9	–0.4	59.1	1.0	62.1
NAIP11 (N11)	54.4	–2.1	49.5	46.9	–2.2	40.2	–3.0	36.8	–0.7	36.0

Source: ReSAKSS based on World Bank (2024) and ILO (2024).

Note: Data only available up to 2021. For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 2a: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.1*

TABLE L2.1.1—AGRICULTURE VALUE ADDED (billion, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	194.7	4.6	235.4	244.3	2.6	300.8	2.4	385.0	3.5	439.5
Central	13.5	–4.7	11.4	11.9	2.7	15.4	4.1	20.7	3.0	22.7
Eastern	44.9	2.1	47.8	54.7	6.2	70.4	2.7	87.8	3.0	98.0
Northern	43.6	7.6	54.2	54.6	0.5	65.8	2.9	86.1	3.3	96.7
Southern	16.6	1.1	17.1	18.0	3.9	21.5	2.6	28.9	3.7	35.7
Western	76.1	6.7	105.1	105.0	1.6	127.7	1.8	161.5	3.8	186.4
Less favorable agriculture conditions	7.2	3.5	8.2	9.3	5.0	11.5	4.6	16.5	4.1	19.8
More favorable agriculture conditions	25.4	0.5	26.7	32.5	8.6	50.3	5.8	72.9	5.2	87.6
Mineral-rich countries	25.2	1.5	25.8	28.1	5.0	31.3	–1.6	26.6	–3.9	22.1
Lower middle-income countries	128.0	6.1	163.7	164.4	1.1	197.2	2.3	256.2	3.8	296.4
Upper middle-income countries	8.9	3.2	10.9	10.1	0.0	10.4	–0.3	12.7	1.2	13.7
CEN-SAD	140.0	5.4	177.4	180.8	1.9	212.0	1.1	255.7	2.9	284.7
COMESA	83.4	1.8	88.1	95.1	3.7	112.9	1.5	136.9	3.2	155.3
EAC	27.6	–2.0	25.8	28.0	3.6	37.5	4.6	51.3	2.8	52.5
ECCAS	14.5	–4.2	12.5	13.2	2.6	17.0	4.3	23.4	3.4	26.2
ECOWAS	76.1	6.7	105.1	105.0	1.6	127.7	1.8	161.5	3.8	186.4
IGAD	36.0	2.1	37.8	43.6	6.8	55.6	2.0	66.4	2.8	74.0
SADC	29.3	–1.6	28.0	29.7	3.6	35.8	2.7	47.0	3.3	53.1
UMA	17.4	13.2	24.6	23.8	–2.1	29.8	6.3	43.0	2.7	46.9
CAADP Compact 2007–09 (CC1)	76.4	6.5	105.0	107.9	2.9	137.2	2.5	176.9	4.3	208.8
CAADP Compact 2010–12 (CC2)	39.8	–0.7	39.1	41.8	2.9	54.4	4.2	78.2	4.6	90.7
CAADP Compact 2013–15 (CC3)	28.1	3.0	30.2	32.8	4.0	35.0	–0.5	35.0	–2.0	33.7
CAADP Compact not yet (CC0)	50.4	6.6	61.1	61.9	1.1	74.2	2.3	94.9	3.1	106.4
CAADP Level 0 (CL0)	50.4	6.6	61.1	61.9	1.1	74.2	2.3	94.9	3.1	106.4
CAADP Level 1 (CL1)	25.3	2.9	27.0	29.5	4.2	30.9	–1.1	29.3	–3.0	27.2
CAADP Level 2 (CL2)	12.2	–4.8	10.2	10.6	2.4	13.7	4.0	19.9	5.0	23.4
CAADP Level 3 (CL3)	12.2	3.9	13.7	15.3	4.9	21.4	3.8	26.8	4.0	31.9
CAADP Level 4 (CL4)	94.5	5.2	123.4	127.1	2.6	160.7	2.8	214.2	4.3	250.5
NAIP00 (N00)	15.1	13.9	20.0	19.7	0.6	25.9	6.4	40.9	3.8	48.4
NAIP01 (N01)	42.4	3.5	48.5	50.3	1.7	58.4	1.1	70.0	2.9	77.6
NAIP10 (N10)	7.5	–9.5	4.9	5.0	3.0	7.0	3.6	9.4	4.3	10.7
NAIP11 (N11)	129.5	4.8	161.8	169.0	3.0	209.2	2.2	264.3	3.5	302.3

Source: ReSAKSS based on World Bank (2024) and FAO (2024).

Note: Aggregate value for a group is the sum of agriculture value added for countries in the group.

ANNEX 2b: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.2*

TABLE L2.1.2—AGRICULTURAL PRODUCTION INDEX (API) (2014-2016 = 100)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	61.4	2.8	69.4	75.8	3.0	88.1	3.2	108.6	2.6	118.3
Central	53.1	0.3	54.9	59.5	3.4	83.1	7.4	107.4	2.4	116.4
Eastern	59.4	2.8	67.5	73.9	3.3	88.5	4.1	108.0	2.7	117.6
Northern	63.5	2.6	72.5	79.8	3.3	92.6	2.3	104.2	1.3	109.1
Southern	68.6	1.8	71.7	75.1	1.9	93.0	3.9	111.2	3.2	124.0
Western	60.8	3.3	69.6	76.4	3.1	85.4	2.6	110.8	3.2	122.6
Less favorable agriculture conditions	53.8	2.6	60.4	66.5	4.4	86.4	3.9	113.3	3.7	123.6
More favorable agriculture conditions	56.3	2.9	64.3	69.8	3.0	87.2	4.8	109.8	3.0	120.9
Mineral-rich countries	52.9	1.3	56.6	60.0	2.5	85.6	7.7	109.3	3.1	123.0
Lower middle-income countries	62.5	2.7	70.5	77.9	3.3	88.2	2.5	108.0	2.5	117.3
Upper middle-income countries	73.7	2.6	81.3	84.5	1.7	95.7	2.0	104.1	1.3	109.9
CEN-SAD	62.5	3.3	71.6	78.7	3.2	88.5	2.4	108.8	2.7	118.9
COMESA	65.7	3.0	74.2	80.0	2.8	91.8	2.7	106.7	2.3	115.7
EAC	61.0	2.5	68.8	74.0	2.6	89.0	5.0	108.1	3.0	120.3
ECCAS	50.9	1.4	55.2	60.5	3.9	85.2	6.7	107.9	2.6	117.8
ECOWAS	60.8	3.3	69.6	76.4	3.1	85.4	2.6	110.8	3.2	122.6
IGAD	60.4	3.2	69.5	75.8	2.8	88.8	3.7	109.2	3.0	119.9
SADC	61.5	1.4	65.0	69.0	2.5	88.6	5.4	108.2	2.6	118.8
UMA	57.2	1.6	65.4	70.6	1.2	88.4	4.7	105.9	1.5	109.1
CAADP Compact 2007–09 (CC1)	59.2	3.6	69.1	75.6	3.1	85.5	2.9	109.5	2.8	119.5
CAADP Compact 2010–12 (CC2)	60.0	2.3	66.1	71.5	2.7	87.8	4.8	112.2	3.8	127.6
CAADP Compact 2013–15 (CC3)	60.0	2.3	66.1	71.5	2.7	87.8	4.8	112.2	3.8	127.6
CAADP Compact not yet (CC0)	64.5	2.4	72.9	79.9	3.3	92.9	2.3	104.2	1.3	109.2
CAADP Level 0 (CL0)	64.5	2.4	72.9	79.9	3.3	92.9	2.3	104.2	1.3	109.2
CAADP Level 1 (CL1)	71.7	0.5	71.8	76.5	2.0	91.3	3.4	107.8	2.4	116.1
CAADP Level 2 (CL2)	51.6	0.6	53.4	58.5	3.5	82.4	7.6	108.6	2.8	120.1
CAADP Level 3 (CL3)	69.1	2.4	76.7	79.7	1.0	91.8	3.2	112.7	4.0	129.1
CAADP Level 4 (CL4)	58.8	3.4	68.1	74.8	3.2	85.6	3.2	110.0	3.0	120.9
NAIP00 (N00)	55.1	0.6	60.3	66.5	3.3	87.1	5.1	106.4	1.9	111.9
NAIP01 (N01)	67.3	3.2	76.7	83.8	3.2	95.0	1.5	103.6	1.2	109.4
NAIP10 (N10)	52.4	–0.8	51.2	52.0	0.6	80.5	11.0	108.8	3.0	121.6
NAIP11 (N11)	60.7	3.1	68.9	75.2	3.0	86.4	3.3	110.2	3.1	121.5

Source: ReSAKSS based on FAO (2024) and World Bank (2024).

Note: Data only available up to 2022. For regions or groups, level is weighted average, where weight is country's share in total agriculture value added for the region or group.

ANNEX 2c: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.3*

TABLE L2.1.3—LABOR PRODUCTIVITY (agriculture value-added per agricultural worker, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	1,363.8	1.7	1,467.2	1,410.1	−0.5	1,554.8	1.2	1,769.6	1.7	1,889.0
Central	669.7	−6.8	489.4	463.1	−0.5	546.2	3.3	657.9	0.8	658.2
Eastern	819.8	−0.9	773.8	828.7	3.8	957.4	0.8	1,021.8	0.9	1,050.1
Northern	3,995.4	3.4	4,218.8	3,945.2	−1.6	4,772.2	4.1	7,352.2	5.9	8,818.1
Southern	897.1	−1.9	792.2	793.0	1.7	859.0	0.9	1,002.3	2.4	1,241.8
Western	2,025.1	4.5	2,625.8	2,381.0	−3.5	2,443.9	1.0	2,762.1	1.3	2,889.3
Less favorable agriculture conditions	668.5	0.6	648.2	615.4	−0.9	633.3	2.5	793.3	1.2	833.0
More favorable agriculture conditions	417.5	−2.2	392.8	449.1	6.3	630.7	3.9	779.4	3.2	877.0
Mineral-rich countries	1,162.9	−1.1	1,072.1	1,114.7	3.5	1,157.4	−2.3	890.7	−6.0	666.2
Lower middle-income countries	2,833.9	3.2	3,242.8	2,941.7	−3.6	3,077.4	1.7	3,727.7	2.4	4,058.7
Upper middle-income countries	2,361.4	−0.1	2,399.7	2,335.8	1.7	2,585.3	1.8	2,898.4	−0.5	3,011.5
CEN-SAD	2,495.5	3.2	2,883.1	2,639.3	−2.7	2,659.3	0.4	2,978.1	1.3	3,093.2
COMESA	1,157.7	−1.2	1,062.8	1,076.0	1.5	1,172.0	0.1	1,259.2	1.8	1,346.7
EAC	673.0	−4.3	568.3	590.1	1.9	732.7	3.4	936.4	4.0	1,138.6
ECCAS	745.8	−6.8	535.0	517.4	−0.2	622.3	3.9	807.3	1.6	871.9
ECOWAS	2,025.1	4.5	2,625.8	2,381.0	−3.5	2,443.9	1.0	2,762.1	1.3	2,889.3
IGAD	1,054.5	−0.9	971.8	1,028.9	3.7	1,155.3	0.0	1,180.0	0.9	1,219.2
SADC	630.0	−4.0	534.5	548.7	2.4	641.8	2.1	757.1	1.5	826.1
UMA	3,144.6	3.9	3,404.4	3,341.4	−0.6	4,646.1	8.1	7,647.1	4.2	8,707.3
CAADP Compact 2007–09 (CC1)	1,386.2	3.6	1,727.7	1,613.5	−1.2	1,801.3	1.1	2,057.3	2.1	2,228.6
CAADP Compact 2010–12 (CC2)	708.9	−2.7	639.7	651.2	0.6	751.4	2.9	934.9	2.4	1,010.2
CAADP Compact 2013–15 (CC3)	1,665.3	−1.2	1,406.5	1,340.2	−0.3	1,269.4	−2.4	1,084.3	−3.9	954.2
CAADP Compact not yet (CC0)	3,585.5	3.3	3,823.8	3,640.8	−0.6	4,453.7	3.9	6,334.3	4.4	7,367.6
CAADP Level 0 (CL0)	3,585.5	3.3	3,823.8	3,640.8	−0.6	4,453.7	3.9	6,334.3	4.4	7,367.6
CAADP Level 1 (CL1)	1,977.5	−1.7	1,586.8	1,489.3	−0.7	1,336.8	−3.8	1,049.2	−4.9	889.0
CAADP Level 2 (CL2)	619.3	−7.0	464.6	467.7	1.4	580.3	3.8	768.8	3.0	836.2
CAADP Level 3 (CL3)	655.5	0.9	655.5	667.5	1.3	795.7	1.5	827.5	0.9	869.0
CAADP Level 4 (CL4)	1,228.7	2.8	1,477.4	1,409.3	−0.9	1,567.3	1.6	1,853.1	2.5	2,043.2
NAIP00 (N00)	3,054.2	3.2	2,705.3	2,503.4	−2.1	2,900.3	4.1	3,735.7	0.4	3,898.1
NAIP01 (N01)	2,687.7	0.7	2,557.0	2,291.2	−2.6	2,444.4	0.3	2,844.9	3.2	3,133.8
NAIP10 (N10)	567.3	−11.6	327.1	328.3	2.0	424.6	2.9	506.2	2.1	531.0
NAIP11 (N11)	1,196.1	2.3	1,369.2	1,327.5	−0.2	1,457.1	1.0	1,623.6	1.5	1,728.7

Source: ReSAKSS based on World Bank (2024).

ANNEX 2d: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.4

TABLE L2.1.4—LAND PRODUCTIVITY (agriculture value-added per hectare of arable land, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	195.7	3.3	227.1	232.6	2.1	282.0	2.4	356.5	3.2	403.6
Central	138.1	–4.7	116.0	121.1	2.6	143.4	2.1	181.7	2.5	195.7
Eastern	161.1	1.5	167.9	188.3	5.5	247.2	4.4	316.9	2.8	351.9
Northern	403.2	–0.6	389.4	391.4	0.4	469.4	2.8	613.2	3.3	688.6
Southern	57.3	0.8	58.5	61.6	3.8	72.9	2.5	97.7	3.8	121.4
Western	348.0	5.9	469.4	457.6	0.7	535.4	1.1	641.4	3.1	724.1
Less favorable agriculture conditions	53.8	3.0	60.9	65.8	3.6	82.2	4.6	115.2	3.9	136.8
More favorable agriculture conditions	143.7	–0.4	146.1	173.0	7.5	256.9	5.1	358.8	4.8	427.3
Mineral-rich countries	127.8	1.0	128.3	137.7	4.6	153.8	0.1	134.7	–4.3	109.5
Lower middle-income countries	396.9	3.8	480.5	479.7	0.9	565.8	1.9	718.3	3.6	824.0
Upper middle-income countries	52.7	2.1	60.6	56.3	0.1	58.3	–0.2	71.3	1.2	76.4
CEN-SAD	272.1	4.6	332.7	334.2	1.4	388.6	1.6	465.8	2.5	512.5
COMESA	252.4	0.7	251.4	267.2	3.2	318.8	2.5	394.5	3.3	453.7
EAC	270.1	–2.2	248.8	265.7	2.8	332.2	3.1	463.7	5.8	606.6
ECCAS	116.3	–3.5	103.2	110.7	3.4	141.5	4.0	199.3	3.6	234.3
ECOWAS	348.0	5.9	469.4	457.6	0.7	535.4	1.1	641.4	3.1	724.1
IGAD	177.3	1.8	182.8	205.9	6.0	272.5	4.4	340.5	2.6	378.0
SADC	81.5	–1.8	77.3	82.4	3.7	100.8	3.1	136.3	3.5	159.1
UMA	160.6	4.3	181.6	174.6	–2.2	218.2	6.2	315.1	2.7	343.9
CAADP Compact 2007–09 (CC1)	384.1	5.6	513.4	511.8	1.8	626.9	1.9	778.7	3.8	904.7
CAADP Compact 2010–12 (CC2)	154.4	–1.0	149.5	157.2	2.2	192.1	2.9	259.8	4.1	296.9
CAADP Compact 2013–15 (CC3)	92.8	2.5	98.2	105.6	3.7	115.7	1.2	120.8	–2.0	116.0
CAADP Compact not yet (CC0)	214.5	2.8	232.3	234.8	1.1	283.0	2.4	362.3	3.1	406.3
CAADP Level 0 (CL0)	214.5	2.8	232.3	234.8	1.1	283.0	2.4	362.3	3.1	406.3
CAADP Level 1 (CL1)	85.9	2.4	90.1	97.5	4.0	105.0	0.6	104.0	–3.1	96.5
CAADP Level 2 (CL2)	136.7	–4.8	113.6	118.1	2.3	137.9	1.6	184.3	4.4	212.3
CAADP Level 3 (CL3)	102.3	2.6	109.8	117.7	3.6	157.5	3.2	191.7	3.7	226.2
CAADP Level 4 (CL4)	369.5	4.9	475.3	479.5	1.8	583.2	2.2	740.5	3.8	851.3
NAIP00 (N00)	71.6	10.2	89.3	87.8	0.6	115.3	6.4	182.0	3.7	215.1
NAIP01 (N01)	257.9	2.0	273.1	282.4	1.6	328.1	1.0	391.3	2.9	433.8
NAIP10 (N10)	278.2	–9.4	180.9	187.6	2.8	202.1	–1.4	232.5	3.1	254.5
NAIP11 (N11)	217.4	4.3	266.2	272.4	2.3	332.9	2.6	416.1	3.2	470.8

Source: ReSAKSS based on World Bank (2024) and FAO (2024).

ANNEX 2e: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5A

TABLE L2.1.5A—YIELD, CASSAVA (metric tons per hectare)										
Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	8.6	1.0	8.9	9.3	1.8	9.0	−2.7	8.3	−0.8	8.1
Central	7.8	−0.2	7.6	7.8	1.3	8.2	0.8	8.5	−0.2	8.5
Eastern	8.0	0.1	7.7	7.6	1.0	6.2	−3.2	5.3	1.0	5.7
Northern										
Southern	6.4	8.3	8.0	8.5	3.0	9.4	0.6	10.5	4.0	10.9
Western	10.1	−0.4	10.3	10.8	1.5	10.3	−5.4	8.7	−2.6	7.7
Less favorable agriculture conditions	7.1	7.1	8.3	7.4	−6.0	7.4	5.8	9.8	2.2	10.3
More favorable agriculture conditions	7.5	3.0	7.7	7.6	0.6	6.9	−0.9	6.8	2.2	7.3
Mineral-rich countries	7.5	−0.4	7.3	7.3	0.0	7.9	2.1	8.6	0.3	8.6
Lower middle-income countries	9.9	0.2	10.4	11.1	2.8	10.9	−6.0	8.8	−2.4	7.9
Upper middle-income countries	4.2	0.5	4.3	4.3	0.9	4.5	0.9	4.6	0.0	4.6
CEN-SAD	9.8	−0.3	10.0	10.5	1.4	10.1	−4.8	8.6	−2.6	7.7
COMESA	8.1	2.4	8.6	8.7	−0.2	8.1	−0.8	8.2	0.4	8.4
EAC	8.2	0.1	8.1	7.9	−0.2	7.3	−0.4	7.0	−1.2	6.6
ECCAS	7.6	1.9	8.3	8.7	2.4	9.2	−1.2	8.6	0.1	8.7
ECOWAS	10.1	−0.4	10.3	10.8	1.5	10.3	−5.4	8.7	−2.6	7.7
IGAD	10.3	9.2	12.8	12.1	−7.3	5.7	−12.2	3.3	−2.8	3.4
SADC	7.3	1.3	7.5	7.8	2.8	8.2	0.3	8.5	1.5	8.6
UMA										
CAADP Compact 2007–09 (CC1)	10.3	−0.7	10.4	10.9	1.5	10.5	−5.4	8.9	−2.7	7.9
CAADP Compact 2010–12 (CC2)	7.4	1.4	7.5	7.4	0.1	7.2	0.7	7.6	1.1	7.8
CAADP Compact 2013–15 (CC3)	7.3	4.3	8.5	9.7	6.5	11.2	−2.5	9.6	1.2	10.0
CAADP Compact not yet (CC0)	7.1	0.7	7.3	7.4	0.4	7.6	0.3	7.7	0.2	7.8
CAADP Level 0 (CL0)	7.1	0.7	7.3	7.4	0.4	7.6	0.3	7.7	0.2	7.8
CAADP Level 1 (CL1)	6.9	6.5	8.9	9.6	4.6	10.7	−3.3	8.6	1.2	9.1
CAADP Level 2 (CL2)	7.8	−0.5	7.6	7.9	1.7	8.4	0.6	8.5	−0.1	8.5
CAADP Level 3 (CL3)	8.2	5.3	9.0	8.5	−4.3	6.2	−3.1	6.2	1.5	7.1
CAADP Level 4 (CL4)	9.2	0.1	9.4	9.8	2.1	9.5	−3.4	8.6	−1.7	7.9
NAIP00 (N00)	7.0	11.9	10.8	11.7	5.6	13.0	−5.9	9.1	1.5	9.8
NAIP01 (N01)	6.6	0.5	6.1	6.8	4.5	7.2	0.7	7.4	0.2	7.4
NAIP10 (N10)	7.7	−0.1	7.7	7.6	−0.2	7.9	1.2	8.1	−0.3	8.1
NAIP11 (N11)	9.1	0.4	9.2	9.6	1.8	9.1	−3.3	8.4	−1.2	8.0

Source: ReSAKSS based on FAO (2024).

Note: Data only available up to 2022. Cassava production data are not available in Northern Africa and UMA.

ANNEX 2f: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5B

TABLE L2.1.5B—YIELD, YAMS (metric tons per hectare)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	10.2	−0.5	10.4	10.7	0.2	9.3	−5.9	8.7	−0.8	8.4
Central	7.4	0.1	7.2	7.7	3.4	8.3	−0.2	7.9	−1.5	7.5
Eastern	10.6	1.1	11.5	11.1	−2.5	7.3	−22.4	3.0	−0.4	2.9
Northern	6.3	−0.1	6.3	6.3	0.0	6.3	−0.1	6.3	0.0	6.3
Southern										
Western	10.3	−0.6	10.5	10.8	0.2	9.4	−5.9	8.8	−0.8	8.4
Less favorable agriculture conditions	8.8	1.7	9.3	9.8	2.3	10.3	1.1	10.2	0.0	10.3
More favorable agriculture conditions	10.3	2.2	11.5	11.1	−0.1	12.1	0.4	12.2	−0.6	11.6
Mineral-rich countries	8.7	−1.2	8.2	8.3	0.6	7.1	−12.5	4.9	1.5	5.1
Lower middle-income countries	10.2	−0.8	10.4	10.8	0.2	9.3	−6.1	8.6	−0.8	8.3
Upper middle-income countries	7.2	1.4	7.4	7.5	0.3	6.6	−3.3	6.2	0.5	6.3
CEN-SAD	10.3	−0.6	10.5	10.8	0.2	9.4	−6.0	8.7	−0.8	8.4
COMESA	9.2	−0.9	8.9	8.7	−1.1	6.5	−17.5	3.4	−0.3	3.3
EAC	5.3	0.5	5.4	5.6	−0.3	5.6	−2.4	4.4	−1.4	4.3
ECCAS	7.4	0.1	7.1	7.7	3.3	8.3	0.1	7.9	−1.5	7.6
ECOWAS	10.3	−0.6	10.5	10.8	0.2	9.4	−5.9	8.8	−0.8	8.4
IGAD	11.3	1.1	12.5	12.2	−2.1	7.7	−27.2	2.5	−0.5	2.4
SADC	5.9	−5.6	4.5	4.5	0.1	4.5	−0.1	4.6	0.1	4.6
UMA	6.3	−0.1	6.3	6.3	0.0	6.3	−0.1	6.3	0.0	6.3
CAADP Compact 2007–09 (CC1)	10.4	−0.4	10.8	11.3	0.8	10.0	−6.7	9.4	−0.8	8.9
CAADP Compact 2010–12 (CC2)	8.8	−1.2	8.4	8.1	−2.3	6.8	−1.4	5.9	−1.7	5.6
CAADP Compact 2013–15 (CC3)	10.1	−0.1	9.6	10.5	3.6	8.9	−10.6	6.1	−1.7	5.8
CAADP Compact not yet (CC0)	5.3	0.1	5.3	5.3	0.2	4.4	−11.3	3.1	0.5	3.1
CAADP Level 0 (CL0)	5.3	0.1	5.3	5.3	0.2	4.4	−11.3	3.1	0.5	3.1
CAADP Level 1 (CL1)	11.1	0.3	11.1	11.0	−0.6	8.1	−14.3	5.1	0.0	5.1
CAADP Level 2 (CL2)	7.3	−0.6	6.8	7.5	4.7	8.6	0.0	7.9	−1.9	7.5
CAADP Level 3 (CL3)	10.0	3.2	10.6	10.7	0.6	9.9	−3.4	9.3	0.8	9.5
CAADP Level 4 (CL4)	10.2	−0.6	10.5	10.8	0.2	9.4	−5.8	8.8	−0.9	8.4
NAIP00 (N00)										
NAIP01 (N01)	8.4	0.4	8.5	8.6	0.2	8.2	−1.0	8.0	0.1	8.0
NAIP10 (N10)	6.5	−1.2	6.1	6.3	1.4	6.8	0.7	7.2	0.0	7.1
NAIP11 (N11)	10.3	−0.6	10.5	10.8	0.2	9.4	−6.0	8.7	−0.8	8.4

Source: ReSAKSS based on FAO (2024).

Note: Data only available up to 2022. Yam production data are not available for Southern Africa.

ANNEX 2g: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5C

TABLE L2.1.5C—YIELD, MAIZE (metric tons per hectare)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	1.7	1.5	1.7	1.7	2.3	2.0	0.7	2.1	1.8	2.3
Central	1.1	0.3	1.1	1.1	1.6	1.1	−0.9	1.1	0.0	1.1
Eastern	1.6	0.2	1.6	1.5	4.5	1.8	3.6	2.2	2.5	2.4
Northern	5.5	3.6	6.1	6.3	0.8	6.5	1.4	6.6	0.1	7.1
Southern	1.6	2.0	1.6	1.7	2.2	2.2	2.9	2.3	2.3	2.6
Western	1.4	1.9	1.5	1.6	2.0	1.7	−2.2	1.8	2.5	2.0
Less favorable agriculture conditions	1.1	0.4	1.2	1.3	2.4	1.8	1.6	2.0	2.0	2.0
More favorable agriculture conditions	1.4	0.2	1.3	1.3	5.5	1.7	3.7	2.0	2.0	2.2
Mineral-rich countries	0.9	0.9	0.9	0.9	0.0	0.9	−1.2	0.9	0.3	0.9
Lower middle-income countries	1.8	1.9	1.9	1.9	0.2	2.0	0.0	2.1	1.3	2.2
Upper middle-income countries	2.4	5.1	2.8	3.3	6.7	4.5	0.3	4.7	3.2	5.2
CEN-SAD	1.9	2.3	2.0	2.1	0.6	2.1	−1.9	2.1	1.1	2.2
COMESA	1.8	0.7	1.8	1.9	1.8	2.2	3.3	2.4	1.9	2.6
EAC	1.6	−0.6	1.5	1.4	4.3	1.6	2.1	1.8	0.8	1.8
ECCAS	0.9	0.5	0.9	1.0	1.3	1.1	1.2	1.1	0.3	1.1
ECOWAS	1.4	1.9	1.5	1.6	2.0	1.7	−2.2	1.8	2.5	2.0
IGAD	1.6	1.3	1.6	1.7	2.4	2.1	4.4	2.7	4.1	3.0
SADC	1.5	1.1	1.5	1.5	3.0	1.8	1.6	1.9	1.7	2.1
UMA	0.6	2.9	0.8	0.7	−1.9	0.8	−1.1	0.7	−5.2	0.6
CAADP Compact 2007–09 (CC1)	1.4	1.4	1.5	1.6	3.7	1.8	0.2	2.2	3.2	2.4
CAADP Compact 2010–12 (CC2)	1.4	−0.2	1.3	1.3	3.4	1.5	2.2	1.6	0.8	1.7
CAADP Compact 2013–15 (CC3)	1.0	0.0	1.0	1.0	−3.2	1.1	5.9	1.3	2.0	1.3
CAADP Compact not yet (CC0)	3.0	4.6	3.5	4.0	5.8	4.9	−0.8	5.0	2.1	5.4
CAADP Level 0 (CL0)	3.0	4.6	3.5	4.0	5.8	4.9	−0.8	5.0	2.1	5.4
CAADP Level 1 (CL1)	0.9	−1.5	0.8	0.8	−6.0	0.9	8.9	1.1	2.9	1.2
CAADP Level 2 (CL2)	1.1	1.3	1.1	1.1	0.9	1.1	−1.6	1.1	0.3	1.1
CAADP Level 3 (CL3)	1.4	1.7	1.5	1.6	3.4	2.1	1.8	2.4	1.6	2.6
CAADP Level 4 (CL4)	1.4	0.4	1.4	1.5	3.9	1.7	1.6	1.9	2.2	2.1
NAIP00 (N00)	2.0	4.4	2.3	2.5	4.6	3.2	−0.1	3.0	1.8	3.3
NAIP01 (N01)	4.3	3.2	4.8	4.8	−1.0	4.7	0.8	4.8	0.1	5.1
NAIP10 (N10)	0.8	−0.9	0.8	0.8	−0.5	0.8	−0.1	0.8	−0.1	0.8
NAIP11 (N11)	1.4	0.5	1.4	1.4	3.0	1.7	2.0	1.9	2.3	2.1

Source: ReSAKSS based on FAO (2024).
Note: Data only available up to 2022.

ANNEX 2h: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5D

TABLE L2.1.5D—YIELD, MEAT (cattle, kilograms per head)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014–2022)	Annual avg. change (%) (2014–2022)	2022
Africa	150.4	0.7	156.8	160.8	0.9	162.4	−0.4	159.0	0.1	160.3
Central	134.4	−0.2	133.0	132.4	0.0	130.6	−0.2	131.6	−0.4	130.1
Eastern	115.3	1.0	125.5	130.0	1.0	128.1	−1.1	119.8	−0.1	121.4
Northern	191.7	3.0	223.6	228.6	1.7	237.0	−0.1	249.8	1.3	261.2
Southern	216.5	−0.2	214.7	224.4	1.2	232.8	0.2	244.6	1.2	252.4
Western	125.9	0.4	127.4	127.2	0.1	125.0	−0.6	119.5	−0.2	117.7
Less favorable agriculture conditions	123.4	1.1	127.6	127.4	−0.3	124.0	−0.3	123.0	−0.2	122.3
More favorable agriculture conditions	113.3	−0.6	111.2	112.5	0.5	113.0	−0.2	121.5	1.8	125.3
Mineral-rich countries	121.6	1.3	127.1	126.9	0.1	130.1	0.1	129.9	−0.1	128.4
Lower middle-income countries	165.3	1.7	183.1	189.8	1.4	191.2	−0.8	178.6	−0.1	184.1
Upper middle-income countries	244.9	−0.5	240.9	258.8	1.6	285.6	1.4	300.8	1.0	307.3
CEN-SAD	135.2	1.7	149.8	154.0	1.2	153.6	−1.2	138.6	−0.7	137.9
COMESA	148.0	1.3	160.7	165.0	1.1	167.2	−0.9	155.1	0.0	160.2
EAC	121.9	1.5	142.4	152.4	2.0	147.5	−1.8	131.7	−0.1	134.8
ECCAS	139.9	0.2	138.3	135.7	−0.4	132.6	−0.2	132.6	−0.5	130.7
ECOWAS	125.9	0.4	127.4	127.2	0.1	125.0	−0.6	119.5	−0.2	117.7
IGAD	118.2	1.7	132.4	138.2	1.2	137.0	−1.4	119.1	−1.3	117.7
SADC	186.8	−0.2	185.5	192.0	1.0	196.5	0.1	208.3	1.3	215.0
UMA	180.5	1.1	184.4	185.6	0.8	189.4	0.9	214.4	1.7	225.8
CAADP Compact 2007–09 (CC1)	123.3	0.2	123.8	124.0	0.1	120.1	−0.9	114.4	−0.8	112.4
CAADP Compact 2010–12 (CC2)	123.0	0.8	134.6	140.7	1.5	141.1	−0.8	132.8	0.3	135.5
CAADP Compact 2013–15 (CC3)	153.5	0.5	153.8	152.6	−0.1	152.4	−0.8	150.2	0.6	153.9
CAADP Compact not yet (CC0)	206.6	1.2	222.2	232.9	1.7	245.9	0.1	251.4	0.7	257.2
CAADP Level 0 (CL0)	206.6	1.2	222.2	232.9	1.7	245.9	0.1	251.4	0.7	257.2
CAADP Level 1 (CL1)	154.5	0.6	155.1	153.8	−0.1	153.9	−0.8	150.7	0.7	155.0
CAADP Level 2 (CL2)	136.6	−0.7	133.0	131.3	−0.1	133.8	1.1	144.4	−0.6	138.3
CAADP Level 3 (CL3)	147.2	2.7	160.2	162.2	0.4	161.0	−0.6	166.3	0.0	162.2
CAADP Level 4 (CL4)	117.6	0.4	124.3	128.6	1.2	126.2	−1.2	114.8	0.0	117.3
NAIP00 (N00)	213.7	−0.1	213.7	225.9	1.4	243.5	1.0	259.3	1.1	265.4
NAIP01 (N01)	165.0	1.8	182.3	182.4	0.7	184.4	−0.4	178.7	−0.4	176.3
NAIP10 (N10)	163.7	0.0	162.7	160.6	0.2	164.0	0.5	166.9	0.1	167.4
NAIP11 (N11)	133.2	0.6	138.3	140.9	0.7	140.4	−0.8	134.7	0.2	137.2

Source: ReSAKSS based on FAO (2024).
Note: Data only available up to 2022.

ANNEX 2i: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5E

TABLE L2.1.5E—YIELD, MILK (whole fresh cow, kilograms per head)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	510.7	1.6	548.5	541.1	−0.6	529.5	0.4	556.4	2.4	599.4
Central	339.2	−0.9	328.0	327.7	0.1	332.5	1.6	325.5	−2.2	305.5
Eastern	378.9	2.8	436.6	409.2	−2.5	378.3	−0.4	407.4	3.7	456.4
Northern	1,109.0	5.1	1,312.5	1,522.7	5.4	1,842.3	2.6	1,919.6	2.1	2,071.7
Southern	1,331.1	−1.2	1,343.1	1,417.3	1.0	1,436.2	1.5	1,529.9	0.4	1,531.4
Western	225.1	−0.9	217.2	228.5	2.9	238.6	−0.6	238.3	−0.4	235.5
Less favorable agriculture conditions	283.0	−1.7	260.9	274.9	2.7	279.5	−1.1	273.5	−0.7	264.7
More favorable agriculture conditions	276.3	5.4	377.8	360.6	−2.4	315.1	−0.3	355.6	5.0	400.5
Mineral-rich countries	465.4	−1.7	431.6	392.2	−2.1	383.8	0.0	376.1	0.7	400.9
Lower middle-income countries	652.8	4.6	765.6	814.3	2.1	919.0	1.2	981.4	2.8	1,077.8
Upper middle-income countries	2,292.6	−1.8	2,280.9	2,432.5	0.5	2,331.8	1.6	2,699.0	1.4	2,762.6
CEN-SAD	473.9	1.2	489.3	483.0	0.2	517.2	1.6	561.4	2.4	609.1
COMESA	483.8	2.5	548.9	528.8	−1.5	498.3	0.1	562.7	5.2	650.6
EAC	389.7	3.1	433.3	422.0	−1.8	420.5	0.0	452.5	3.0	513.7
ECCAS	394.1	−0.4	384.2	384.5	0.1	397.0	2.1	378.3	−1.7	360.9
ECOWAS	225.1	−0.9	217.2	228.5	2.9	238.6	−0.6	238.3	−0.4	235.5
IGAD	417.2	2.7	482.7	448.5	−2.7	404.1	−1.1	423.9	3.7	470.9
SADC	643.1	−0.8	615.6	606.9	−1.2	599.5	1.6	673.4	1.7	713.4
UMA	1,073.5	5.6	1,256.2	1,434.5	5.8	1,830.0	4.5	1,844.7	−1.2	1,770.2
CAADP Compact 2007–09 (CC1)	279.4	6.1	410.0	391.8	−2.4	316.6	−2.7	331.7	5.0	362.0
CAADP Compact 2010–12 (CC2)	369.2	2.5	404.5	394.8	−1.4	403.1	1.2	451.1	3.1	505.3
CAADP Compact 2013–15 (CC3)	426.3	−0.4	413.5	381.0	−1.9	374.8	0.5	368.3	0.0	366.9
CAADP Compact not yet (CC0)	1,212.9	2.1	1,307.1	1,468.3	3.7	1,385.2	−7.7	1,105.8	1.6	1,188.2
CAADP Level 0 (CL0)	1,212.9	2.1	1,307.1	1,468.3	3.7	1,385.2	−7.7	1,105.8	1.6	1,188.2
CAADP Level 1 (CL1)	421.2	−0.3	409.5	377.1	−1.9	369.8	0.4	360.9	0.0	359.7
CAADP Level 2 (CL2)	331.0	−0.5	321.8	321.3	0.3	334.8	1.7	346.9	0.2	356.2
CAADP Level 3 (CL3)	427.6	−1.2	406.3	408.5	0.8	407.5	0.0	407.6	−0.8	392.6
CAADP Level 4 (CL4)	313.8	5.5	416.8	398.4	−2.9	355.2	−0.7	401.3	5.6	466.3
NAIP00 (N00)	1,328.5	1.4	1,438.3	1,623.1	3.3	1,829.6	2.9	1,848.2	−0.2	1,843.9
NAIP01 (N01)	757.9	3.6	855.7	933.4	3.1	1,036.2	1.2	1,121.0	3.0	1,227.9
NAIP10 (N10)	286.5	0.0	281.6	281.9	0.5	289.3	0.5	276.9	−0.1	276.7
NAIP11 (N11)	367.7	2.4	414.4	391.6	−2.0	366.5	−0.4	388.3	3.0	427.1

Source: ReSAKSS based on FAO (2024).
Note: Data only available up to 2022.

ANNEX 2j: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.2.1A

TABLE L2.2.1A—INTRA-AFRICAN AGRICULTURAL TRADE, EXPORTS (billion, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	4.9	4.1	5.7	6.4	7.9	11.6	8.3	14.8	3.3	17.6
Central	0.1	1.8	0.2	0.3	3.3	0.7	9.2	0.3	–4.5	0.2
Eastern	1.0	3.5	1.2	1.4	11.1	2.2	5.3	3.1	6.0	3.9
Northern	0.5	8.3	0.7	1.2	18.3	2.0	5.2	2.7	4.9	3.4
Southern	2.4	2.0	2.5	2.4	4.3	5.0	12.8	6.5	0.7	7.0
Western	0.8	9.9	1.1	1.1	4.2	1.7	4.3	2.3	7.0	3.2
Less favorable agriculture conditions	0.2	7.6	0.2	0.2	11.1	0.3	–7.3	0.4	11.9	0.6
More favorable agriculture conditions	0.5	9.3	0.8	1.0	11.8	1.7	8.1	2.4	5.3	3.1
Mineral-rich countries	0.3	7.9	0.4	0.4	0.3	1.1	15.9	1.1	2.8	1.0
Lower middle-income countries	2.5	3.9	2.8	3.2	8.7	5.0	4.7	6.1	3.9	7.6
Upper middle-income countries	1.4	1.7	1.5	1.5	5.9	3.6	13.9	4.8	1.0	5.4
CEN-SAD	2.0	6.3	2.5	3.0	9.3	4.6	3.3	5.9	5.5	7.5
COMESA	2.3	4.0	2.6	3.1	9.6	5.3	6.7	6.2	3.5	7.2
EAC	3.1	3.5	3.7	4.5	9.9	7.6	6.1	8.5	3.6	10.2
ECCAS	1.0	2.3	1.4	1.7	8.9	3.0	5.5	2.8	3.1	3.6
ECOWAS	1.0	8.5	1.4	1.4	3.6	2.5	5.6	2.8	5.6	3.8
IGAD	1.6	5.9	2.0	2.2	7.6	3.3	3.5	4.4	6.5	5.7
SADC	2.9	3.8	3.4	3.6	6.4	7.2	10.2	9.0	2.2	10.2
UMA	3.3	3.1	3.7	4.1	8.5	8.1	10.7	10.1	1.6	11.5
CAADP Compact 2007–09 (CC1)	0.4	10.1	0.6	0.6	8.4	1.2	5.2	1.6	9.7	2.3
CAADP Compact 2010–12 (CC2)	1.8	5.0	2.3	2.8	7.5	4.2	6.0	5.0	3.5	6.1
CAADP Compact 2013–15 (CC3)	0.9	–1.2	0.8	0.7	1.9	0.9	9.6	1.3	–0.9	1.0
CAADP Compact not yet (CC0)	1.8	4.2	2.1	2.4	10.1	5.3	10.8	6.9	2.3	8.2
CAADP Level 0 (CL0)	1.8	4.2	2.1	2.4	10.1	5.3	10.8	6.9	2.3	8.2
CAADP Level 1 (CL1)	1.1	0.0	0.9	0.8	1.9	1.1	6.8	1.6	0.6	1.4
CAADP Level 2 (CL2)	0.2	–2.6	0.3	0.4	9.9	0.8	10.0	0.5	–4.4	0.5
CAADP Level 3 (CL3)	0.4	10.7	0.6	0.8	12.8	1.2	7.3	1.8	5.9	2.3
CAADP Level 4 (CL4)	1.5	6.1	1.8	2.0	6.1	3.2	5.3	4.0	5.9	5.3
NAIP00 (N00)	1.4	1.9	1.5	1.4	4.9	3.5	14.3	4.7	0.8	5.2
NAIP01 (N01)	0.5	10.9	0.8	1.2	16.3	2.1	4.6	2.6	5.1	3.3
NAIP10 (N10)	0.3	3.1	0.4	0.4	1.3	0.8	6.0	0.5	–0.7	0.5
NAIP11 (N11)	2.7	4.0	3.1	3.5	7.5	5.2	6.6	7.0	4.8	8.6

Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

Note: Aggregate value for a group is the sum of intra-African agricultural exports for countries in the group. The values of intra-African agricultural exports and imports for Africa as a whole are expected to be equal. However, Tables L2.2.1A and L2.2.1B show differing values due to differences in commodities categorized as agricultural by different countries, year of shipment of exports and arrival of imports, treatment of the origin of export versus shipment, and valuation of exports and imports (for details see UNCTAD: https://unctadstat.unctad.org/EN/FAQ.html).

ANNEX 2k: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.2.1B

TABLE L2.2.1B—INTRA-AFRICAN AGRICULTURAL TRADE, IMPORTS (billion, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	5.9	6.4	7.5	8.0	3.7	11.9	5.2	14.9	3.6	17.8
Central	0.6	–3.5	0.6	0.8	7.3	1.1	5.9	1.1	–2.0	1.2
Eastern	0.8	10.9	1.2	1.4	6.7	2.2	2.1	2.8	6.3	3.3
Northern	0.9	6.9	1.1	1.1	4.4	1.7	5.3	2.7	7.4	3.8
Southern	2.8	4.6	3.3	3.3	1.8	4.9	6.1	5.5	0.1	5.8
Western	0.9	15.6	1.2	1.3	3.2	2.0	5.8	2.8	7.2	3.8
Less favorable agriculture conditions	0.3	8.7	0.4	0.5	8.5	1.0	6.2	1.2	2.8	1.4
More favorable agriculture conditions	0.7	3.3	0.9	1.1	4.3	1.3	7.3	2.3	6.5	2.7
Mineral-rich countries	0.7	–1.0	0.7	0.8	3.7	1.4	8.0	1.5	0.6	1.6
Lower middle-income countries	3.0	8.6	3.8	3.9	3.0	5.5	2.1	6.4	3.7	7.8
Upper middle-income countries	1.3	6.6	1.6	1.6	3.6	2.7	9.3	3.6	3.2	4.3
CEN-SAD	2.0	12.3	2.9	3.1	3.7	4.9	4.4	6.2	5.9	8.1
COMESA	2.6	5.0	3.5	3.8	3.9	5.5	4.0	6.5	4.5	8.2
EAC	0.7	0.5	1.0	1.3	9.0	1.8	3.2	1.9	1.2	1.9
ECCAS	0.6	–3.4	0.7	0.9	8.7	1.3	7.2	1.4	–0.9	1.5
ECOWAS	0.9	15.6	1.2	1.3	3.2	2.0	5.8	2.8	7.2	3.8
IGAD	0.6	11.2	0.8	1.0	7.6	1.5	–0.5	2.0	7.5	2.3
SADC	2.7	2.3	3.4	3.6	4.3	5.5	6.8	6.3	0.8	6.8
UMA	0.6	6.3	0.7	0.7	2.2	1.2	9.0	2.0	6.8	2.6
CAADP Compact 2007–09 (CC1)	0.8	16.0	1.0	1.0	2.2	1.7	6.9	2.6	9.8	3.8
CAADP Compact 2010–12 (CC2)	1.7	3.8	2.2	2.5	5.1	3.4	4.8	4.4	3.3	5.1
CAADP Compact 2013–15 (CC3)	1.7	6.3	2.1	2.1	0.8	3.0	3.4	2.6	–2.8	2.5
CAADP Compact not yet (CC0)	1.8	5.5	2.2	2.3	5.7	3.8	6.5	5.3	4.3	6.4
CAADP Level 0 (CL0)	1.8	5.5	2.2	2.3	5.7	3.8	6.5	5.3	4.3	6.4
CAADP Level 1 (CL1)	1.9	6.2	2.4	2.3	0.2	3.1	3.3	2.8	–2.2	2.8
CAADP Level 2 (CL2)	0.4	–7.8	0.4	0.6	14.7	0.9	4.7	1.0	2.7	1.2
CAADP Level 3 (CL3)	0.6	7.8	0.7	0.8	4.2	1.0	6.6	1.7	6.9	2.2
CAADP Level 4 (CL4)	1.3	12.7	1.8	2.0	2.7	3.0	5.5	4.2	5.8	5.3
NAIP00 (N00)	1.5	5.5	1.6	1.6	1.9	2.6	6.8	3.3	–0.3	3.3
NAIP01 (N01)	1.3	8.4	1.8	1.8	4.7	2.5	3.4	3.3	5.6	4.4
NAIP10 (N10)	0.6	–3.9	0.6	0.7	7.5	0.9	3.4	0.9	1.5	1.0
NAIP11 (N11)	2.6	8.5	3.5	3.8	3.3	5.9	5.9	7.4	4.6	9.1

Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

Note: Aggregate value for a group is the sum of intra-African agricultural imports for countries in the group. The values of intra-African agricultural exports and imports for Africa as a whole are expected to be equal. However, Tables L2.2.1A and L2.2.1B show differing values due to differences in commodities categorized as agricultural by different countries, year of shipment of exports and arrival of imports, treatment of the origin of export versus shipment, and valuation of exports and imports (for details see UNCTAD: https://unctadstat.unctad.org/EN/FAQ.html).

ANNEX 3a: Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.1

TABLE L3.5.1—GOVERNMENT AGRICULTURE EXPENDITURE (billion, constant 2015 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	10.4	2.3	11.5	13.1	5.4	14.4	1.8	17.5	0.4	17.9
Central	0.5	–27.5	0.2	0.3	12.8	0.5	9.4	0.8	8.4	1.2
Eastern	1.6	3.7	2.1	2.7	9.4	3.2	0.2	4.1	0.6	4.1
Northern	5.3	3.9	5.6	5.2	–3.9	4.0	–1.1	4.4	–0.5	4.3
Southern	1.4	3.2	1.7	2.4	15.6	3.2	1.6	3.1	–2.6	3.2
Western	1.6	5.5	2.0	2.5	11.6	3.5	5.9	5.2	2.0	5.2
Less favorable agriculture conditions	0.4	0.6	0.4	0.5	2.0	0.5	9.7	1.0	4.8	1.1
More favorable agriculture conditions	1.1	5.9	1.5	2.0	13.0	2.9	5.1	4.3	0.8	4.4
Mineral-rich countries	0.9	–16.5	0.6	0.9	13.1	0.8	–0.8	1.3	–1.7	1.2
Lower middle-income countries	7.1	3.2	7.7	7.9	2.4	8.1	0.8	9.0	0.3	9.1
Upper middle-income countries	0.9	13.6	1.4	1.7	8.1	1.9	–0.5	1.9	–0.4	2.1
CEN-SAD	6.9	2.1	7.1	7.1	0.4	7.4	3.1	10.2	1.6	10.5
COMESA	5.5	–1.1	5.2	5.4	1.6	5.7	2.0	7.0	–1.4	6.6
EAC	1.1	–11.4	0.8	0.9	6.0	1.2	–0.2	1.9	3.2	2.1
ECCAS	0.6	–25.9	0.2	0.3	12.9	0.6	11.6	1.0	8.2	1.4
ECOWAS	1.6	5.5	2.0	2.5	11.6	3.5	5.9	5.2	2.0	5.2
IGAD	1.3	3.6	1.7	2.3	10.7	2.5	1.2	3.2	0.0	3.1
SADC	2.0	–4.8	1.9	2.5	10.4	3.4	1.4	3.6	–1.6	3.9
UMA	2.7	3.3	3.1	3.2	1.1	2.5	–3.4	2.6	1.6	2.8
CAADP Compact 2007–09 (CC1)	1.6	12.8	2.3	3.2	13.0	4.2	5.3	5.8	1.0	5.8
CAADP Compact 2010–12 (CC2)	2.4	–6.9	2.0	2.3	6.3	3.0	3.7	4.3	1.5	4.5
CAADP Compact 2013–15 (CC3)	0.9	–8.7	0.8	1.3	18.0	1.6	–3.8	1.4	–0.8	1.4
CAADP Compact not yet (CC0)	5.5	6.2	6.3	6.3	–0.6	5.6	–0.2	6.0	–0.5	6.2
CAADP Level 0 (CL0)	5.5	6.2	6.3	6.3	–0.6	5.6	–0.2	6.0	–0.5	6.2
CAADP Level 1 (CL1)	0.9	–9.6	0.8	1.2	17.1	1.3	–7.3	1.0	–1.4	1.0
CAADP Level 2 (CL2)	1.3	–12.8	0.8	0.8	–1.5	0.7	0.6	0.8	3.0	1.0
CAADP Level 3 (CL3)	0.4	8.3	0.6	0.8	11.9	1.1	7.4	2.1	–0.3	2.0
CAADP Level 4 (CL4)	2.3	6.7	3.0	4.0	12.5	5.7	4.9	7.6	1.4	7.8
NAIP00 (N00)	1.7	13.3	2.6	3.5	10.4	3.1	–5.4	2.3	–3.0	2.3
NAIP01 (N01)	4.2	2.6	4.0	3.4	–7.3	3.2	3.2	4.3	1.7	4.6
NAIP10 (N10)	0.5	–38.7	0.1	0.0	–5.4	0.1	13.8	0.1	12.7	0.2
NAIP11 (N11)	4.1	2.0	4.9	6.2	10.4	8.0	4.1	10.8	0.6	10.9

Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national sources.

Note: Aggregate value for a group is the sum of government agriculture expenditure for countries in the group.

ANNEX 3b: Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.2

TABLE L3.5.2—GOVERNMENT AGRICULTURE EXPENDITURE AS SHARE OF TOTAL GOVERNMENT EXPENDITURE (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	3.7	3.6	3.8	3.6	−4.2	2.6	−0.5	2.8	−0.9	2.8
Central	3.1	−0.2	2.3	2.4	−3.8	2.2	−0.1	2.6	8.7	3.7
Eastern	5.8	1.7	6.1	6.6	3.0	6.5	−4.5	6.1	−2.6	5.4
Northern	5.1	−0.8	4.2	3.5	−9.4	2.0	−4.0	2.2	2.7	2.7
Southern	1.8	5.1	2.3	2.6	4.1	2.4	−2.4	2.0	−1.3	2.3
Western	3.7	−2.9	3.6	3.8	−4.0	2.5	8.4	3.1	−6.4	2.2
Less favorable agriculture conditions	14.6	−4.4	11.5	10.5	−4.9	6.6	0.7	8.3	2.7	8.9
More favorable agriculture conditions	7.7	−2.3	8.0	9.7	5.9	10.0	−2.9	8.6	−3.2	7.4
Mineral-rich countries	4.2	10.7	4.9	4.6	−18.2	1.1	5.0	1.4	−6.1	1.2
Lower middle-income countries	4.1	−0.9	3.6	3.3	−3.8	2.5	−2.4	2.6	0.0	2.7
Upper middle-income countries	1.7	13.2	2.4	2.4	−2.5	1.8	−4.0	1.4	−1.5	1.6
CEN-SAD	5.2	−2.8	4.2	3.6	−8.6	2.4	2.5	3.0	−1.3	2.9
COMESA	5.3	6.7	4.8	4.3	−4.4	3.5	−1.8	4.1	2.2	5.4
EAC	4.5	8.3	3.7	3.2	−0.7	3.6	−7.6	3.8	0.5	3.9
ECCAS	2.1	−4.3	1.5	2.1	8.8	1.9	−3.8	2.4	11.7	3.9
ECOWAS	3.7	−2.9	3.6	3.8	−4.0	2.5	8.4	3.1	−6.4	2.2
IGAD	5.7	2.5	6.4	7.1	4.6	7.0	−2.5	6.9	−1.7	6.7
SADC	2.1	6.0	2.5	2.7	2.2	2.5	−4.1	2.1	−1.5	2.3
UMA	4.9	−1.9	4.3	3.9	−5.0	2.3	−5.8	2.3	2.1	2.5
CAADP Compact 2007–09 (CC1)	3.7	1.6	4.4	5.0	−2.9	3.1	7.6	3.6	−6.9	2.6
CAADP Compact 2010–12 (CC2)	6.4	5.4	4.9	4.5	0.9	4.6	−3.0	4.4	−3.2	3.7
CAADP Compact 2013–15 (CC3)	2.7	−3.0	2.9	3.5	3.4	2.7	−7.8	2.5	6.0	3.7
CAADP Compact not yet (CC0)	3.5	3.5	3.5	3.0	−7.6	1.9	−3.1	2.0	1.6	2.4
CAADP Level 0 (CL0)	3.5	3.5	3.5	3.0	−7.6	1.9	−3.1	2.0	1.6	2.4
CAADP Level 1 (CL1)	2.7	−3.1	2.9	3.4	2.1	2.3	−10.8	2.0	6.7	3.1
CAADP Level 2 (CL2)	11.0	11.2	5.3	4.5	−5.6	3.3	−5.5	2.7	0.6	2.7
CAADP Level 3 (CL3)	5.5	0.9	5.9	5.9	−17.7	1.5	12.4	2.2	−5.4	2.0
CAADP Level 4 (CL4)	4.1	−1.3	4.2	4.8	6.3	5.2	1.3	5.6	−7.0	3.6
NAIP00 (N00)	1.8	11.3	2.6	2.8	−0.1	1.7	−8.3	1.1	−1.7	1.2
NAIP01 (N01)	5.6	−1.5	4.2	3.2	−12.7	2.2	−0.1	3.1	6.6	4.8
NAIP10 (N10)	4.0	−2.5	1.6	1.2	−18.7	0.7	5.9	1.6	15.1	2.4
NAIP11 (N11)	4.8	−1.5	4.7	4.9	−1.3	3.8	3.3	4.0	−5.5	3.1

Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national sources.

ANNEX 3c: *Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.3*

TABLE L3.5.3—GOVERNMENT AGRICULTURE EXPENDITURE AS SHARE OF AGRICULTURE GDP (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	5.5	–1.9	5.0	5.4	2.4	4.8	–0.6	4.6	–3.0	4.1
Central	4.0	–23.9	1.7	2.2	7.8	3.2	5.9	3.8	5.3	5.1
Eastern	3.6	1.6	4.4	5.0	3.1	4.6	–2.5	4.7	–2.4	4.2
Northern	12.4	–2.9	10.9	9.8	–4.8	6.3	–3.9	5.3	–3.9	4.5
Southern	9.0	5.0	11.3	14.9	8.9	15.1	–1.0	10.7	–6.1	9.2
Western	2.2	–1.0	1.9	2.4	9.8	2.7	4.0	3.2	–1.8	2.8
Less favorable agriculture conditions	5.1	–2.8	5.1	5.3	–2.8	4.7	4.8	6.0	0.7	5.6
More favorable agriculture conditions	4.2	5.3	5.4	6.2	4.1	5.9	–0.6	6.0	–4.1	5.0
Mineral-rich countries	3.8	–17.8	2.4	3.0	7.7	2.8	1.3	5.0	2.0	5.5
Lower middle-income countries	5.7	–2.5	4.8	4.9	1.1	4.1	–1.4	3.6	–3.5	3.1
Upper middle-income countries	12.1	13.3	17.7	21.7	3.2	21.8	0.3	16.9	–3.1	16.8
CEN-SAD	5.1	–2.9	4.1	4.0	–1.7	3.5	2.0	4.0	–1.3	3.7
COMESA	6.7	–2.0	6.3	6.0	–2.8	5.1	0.5	5.3	–4.3	4.5
EAC	3.8	–9.6	3.0	3.0	2.7	3.4	–4.7	3.7	0.1	4.0
ECCAS	4.1	–18.2	2.2	3.8	20.6	4.6	–2.2	3.6	1.2	3.8
ECOWAS	2.2	–1.0	1.9	2.4	9.8	2.7	4.0	3.2	–1.8	2.8
IGAD	3.6	1.5	4.5	5.2	4.0	4.6	–0.7	4.9	–2.9	4.2
SADC	6.9	–1.8	7.2	9.2	7.9	9.4	–3.2	6.8	–5.5	6.1
UMA	17.1	–7.5	14.1	14.4	2.1	9.2	–9.3	6.3	–1.5	6.2
CAADP Compact 2007–09 (CC1)	2.0	5.9	2.2	3.0	9.8	3.1	2.7	3.3	–3.2	2.8
CAADP Compact 2010–12 (CC2)	6.0	–6.3	5.2	5.4	3.0	5.5	–0.2	5.6	–2.9	5.0
CAADP Compact 2013–15 (CC3)	3.7	–10.2	3.0	4.2	11.8	4.6	–3.4	3.9	1.2	4.3
CAADP Compact not yet (CC0)	11.1	0.1	10.9	10.5	–2.0	7.9	–2.5	6.5	–3.8	5.9
CAADP Level 0 (CL0)	11.1	0.1	10.9	10.5	–2.0	7.9	–2.5	6.5	–3.8	5.9
CAADP Level 1 (CL1)	4.0	–10.8	3.2	4.4	10.5	4.2	–6.3	3.3	1.6	3.6
CAADP Level 2 (CL2)	10.3	–8.4	8.1	7.3	–4.9	5.3	–2.2	4.3	–1.9	4.2
CAADP Level 3 (CL3)	3.6	4.3	4.4	5.2	6.7	5.1	3.5	8.1	–4.2	6.3
CAADP Level 4 (CL4)	2.4	1.4	2.4	3.1	9.6	3.5	2.0	3.6	–2.8	3.1
NAIP00 (N00)	11.3	–0.6	13.2	17.8	9.8	12.6	–11.0	5.7	–6.5	4.9
NAIP01 (N01)	10.2	–0.3	8.8	7.1	–9.6	5.6	2.1	6.3	–1.5	6.0
NAIP10 (N10)	5.5	–32.3	1.1	1.0	–10.1	0.8	11.7	1.4	8.1	1.7
NAIP11 (N11)	3.2	–2.4	3.1	3.7	7.0	3.9	1.9	4.1	–2.9	3.6

Source: ReSAKSS based on IFPRI (2019), World Bank (2024), and national sources.

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results*

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF SEPTEMBER 2024

Country/Region	JSR assessment conducted/ initiated	First generation NAIP drafted, reviewed, and validated	Second generation investment plan			
			Malabo domestication event held	Malabo status assessment and profile finalized	Malabo goals and milestones report finalized	Malabo compliant NAIP drafted, reviewed, and/or validated
AFRICA*	**23**	**36**	**25**	**31**	**25**	**45**
Central Africa*	**1**	**6**	**2**	**2**	**2**	**5**
Burundi		Yes				Yes
Cameroon		Yes		Yes	Yes	Yes
Central African Republic		Yes				
Chad						Yes
Congo, Dem. Republic	Yes	Yes	Yes			
Congo, Rep. of		Yes				Yes
Equatorial Guinea						
Gabon			Yes	Yes	Yes	Yes
Sao Tome and Principe		Yes				
Eastern Africa*	**6**	**9**	**5**	**6**	**1**	**13**
Comoros						Yes
Djibouti		Yes				Yes
Eritrea						Yes
Ethiopia	Yes	Yes	Yes	Yes		Yes
Kenya	Yes	Yes	Yes	Yes	Yes	Yes
Madagascar						Yes
Mauritius	Yes					Yes
Rwanda		Yes	Yes	Yes		Yes
Seychelles	Yes	Yes		Yes		Yes
Somalia						
South Sudan		Yes				Yes
Sudan		Yes				Yes
Tanzania	Yes	Yes	Yes	Yes		Yes
Uganda	Yes	Yes	Yes	Yes		Yes

continued next page

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results, continued

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF SEPTEMBER 2024, *continued*

Country/Region	JSR assessment conducted/ initiated	First generation NAIP drafted, reviewed, and validated	Second generation investment plan			
			Malabo domestication event held	Malabo status assessment and profile finalized	Malabo goals and milestones report finalized	Malabo compliant NAIP drafted, reviewed, and/or validated
Northern Africa*		**1**				**5**
Algeria						
Egypt						Yes
Libya						Yes
Mauritania		Yes				Yes
Morocco						Yes
Tunisia						Yes
Southern Africa*	**8**	**5**	**9**	**8**	**7**	**7**
Angola	Yes		Yes	Yes	Yes	
Botswana	Yes		Yes	Yes	Yes	Yes
Eswatini	Yes	Yes	Yes	Yes	Yes	Yes
Lesotho			Yes	Yes	Yes	
Malawi	Yes	Yes	Yes	Yes		Yes
Mozambique	Yes	Yes	Yes			Yes
Namibia	Yes		Yes	Yes	Yes	Yes
South Africa						
Zambia	Yes	Yes	Yes	Yes	Yes	Yes
Zimbabwe	Yes	Yes	Yes	Yes	Yes	Yes
Western Africa*	**8**	**15**	**9**	**15**	**15**	**15**
Benin	Yes	Yes	Yes	Yes	Yes	Yes
Burkina Faso	Yes	Yes	Yes	Yes	Yes	Yes
Cabo Verde		Yes		Yes	Yes	Yes
Côte d'Ivoire	Yes	Yes	Yes	Yes	Yes	Yes
Gambia		Yes		Yes	Yes	Yes
Ghana	Yes	Yes	Yes	Yes	Yes	Yes
Guinea		Yes		Yes	Yes	Yes
Guinea-Bissau		Yes		Yes	Yes	Yes

continued next page

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results, continued

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF SEPTEMBER 2024, *continued*

Country/Region	JSR assessment conducted/ initiated	First generation NAIP drafted, reviewed, and validated	Second generation investment plan			
			Malabo domestication event held	Malabo status assessment and profile finalized	Malabo goals and milestones report finalized	Malabo compliant NAIP drafted, reviewed, and/or validated
Western Africa* cont'd	**8**	**15**	**9**	**15**	**15**	**15**
Liberia		Yes		Yes	Yes	Yes
Mali	Yes	Yes	Yes	Yes	Yes	Yes
Niger	Yes	Yes	Yes	Yes	Yes	Yes
Nigeria		Yes	Yes	Yes	Yes	Yes
Senegal	Yes	Yes	Yes	Yes	Yes	Yes
Sierra Leone		Yes		Yes	Yes	Yes
Togo	Yes	Yes	Yes	Yes	Yes	Yes
RECS**	**2**	**3**				
CEN-SAD						
COMESA						
EAC	Yes					
ECCAS		Yes				
ECOWAS	Yes	Yes				
IGAD		Yes				
SADC						
UMA						

Source: Authors' compilation based on NEPAD (November 2015) and ReSAKSS (2024).
Note: * The items in this row are the number of countries in the subregion that have achieved the milestone. ** The items in this row are the number of RECs that have achieved the milestone.
JSR=Joint Sector Review. NAIP= National Agriculture Investment Plan. BR=Biennial Review.

ReSAKSS-ECA

Burundi (COMESA, EAC, ECCAS)
Central African Rep. (CEN-SAD, ECCAS)
Comoros (CEN-SAD, COMESA)
Congo, Dem. Rep. (COMESA, ECCAS, SADC, EAC)
Congo, Rep. (ECCAS)
Djibouti (CEN-SAD, COMESA, IGAD)
Egypt (CEN-SAD, COMESA)
Eritrea (COMESA, IGAD)
Ethiopia (COMESA, IGAD)
Gabon (ECCAS)
Kenya (CEN-SAD, COMESA, EAC, IGAD)
Libya (CEN-SAD, COMESA, UMA)
Rwanda (COMESA, EAC, ECCAS)
Seychelles (COMESA, SADC)
South Sudan (IGAD, EAC)
Sudan (CEN-SAD, COMESA, IGAD)
Tanzania (SADC)
Uganda (COMESA, EAC, IGAD)

ReSAKSS-SA

Angola (ECCAS, SADC)
Botswana (SADC)
Eswatini (COMESA, SADC)
Madagascar (COMESA, SADC)
Malawi (COMESA, SADC)
Mauritius (COMESA, SADC)
Mozambique (SADC)
Namibia (SADC)
Lesotho (SADC)
Zambia (COMESA, SADC)
Zimbabwe (COMESA, SADC)

ReSAKSS-WA

Benin (CEN-SAD, ECOWAS)
Burkina Faso (CEN-SAD, ECOWAS)
Cabo Verde (ECOWAS)
Cameroon (ECCAS)
Chad (CEN-SAD, ECCAS)
Côte d'Ivoire (CEN-SAD, ECOWAS)
Gambia (CEN-SAD, ECOWAS)
Ghana (CEN-SAD, ECOWAS)
Guinea (CEN-SAD, ECOWAS)
Guinea-Bissau (CEN-SAD, ECOWAS)
Liberia (CEN-SAD, ECOWAS)
Mali (CEN-SAD, ECOWAS)
Mauritania (CEN-SAD, UMA)
Niger (CEN-SAD, ECOWAS)
Nigeria (CEN-SAD, ECOWAS)
Senegal (CEN-SAD, ECOWAS)
Sierra Leone (CEN-SAD, ECOWAS)
Togo (CEN-SAD, ECOWAS)

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results, continued*

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY								
Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems, and school feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS***
AFRICA*	**42**	**45**	**28**	**36**	**31**	**22**	**22**	**14**
Central Africa*	**4**	**5**	**2**	**3**	**1**	**3**	**3**	**1**
Burundi	Yes	Yes	Yes	Yes	Yes	Several PPPs	€18 million	
Cameroon		Yes						
Central African Republic	Yes					2	US$1.25	
Chad		Yes						
Congo, Dem. Rep.	Yes		Yes	Yes		Several PPPs	Not stated	Yes
Congo, Rep.	Yes	Yes		Yes				
Equatorial Guinea								
Gabon		Yes						
Sao Tome and Principe								
Eastern Africa*	**14**	**13**	**6**	**12**	**8**	**8**	**8**	**4**
Comoros	Yes	Yes		Yes				
Djibouti	Yes	Yes		Yes		Several PPPs	Not stated	
Eritrea	Yes	Yes						
Ethiopia	Yes	Yes	Yes	Yes	Yes	Several PPPs	Over US$10 million	
Kenya	Yes	Yes		Yes	Yes	Several PPPs	Over US$200 million	Yes
Madagascar	Yes	Yes	Yes	Yes	Yes	4	Not stated	
Mauritius	Yes	Yes	Yes	Yes	Yes	1	Not stated	
Rwanda	Yes	Yes	Yes	Yes	Yes	Several PPPs	Over US$20 million	Yes
Seychelles	Yes	Yes		Yes	Yes			
Somalia	Yes							
South Sudan	Yes	Yes		Yes				
Sudan	Yes	Yes		Yes				

continued next page

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results, continued*

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY, *continued*

Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems, and school feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS***
Eastern Africa* *cont'd*	**14**	**12**	**6**	**12**	**8**	**8**	**8**	**4**
Tanzania	Yes	Yes	Yes	Yes	Yes	Several PPPs across the country and many of them in SAGCOT with several projects	US$ 3.2 billion by 2030	Yes
Uganda	Yes	Yes	Yes	Yes	Yes	Several PPPs	Over US$218 million	Yes
Northern Africa*	**2**	**5**		**2**	**1**	**1**	**1**	
Algeria								
Egypt	Yes	Yes		Yes	Yes	Several PPPs	Over US$30 million	
Libya	Yes	Yes		Yes				
Mauritania		Yes						
Morocco		Yes						
Tunisia		Yes						
Southern Africa*	**10**	**7**	**10**	**10**	**9**	**7**	**7**	**2**
Angola	Yes		Yes	Yes	Yes	5	Not stated	
Botswana	Yes	Yes	Yes	Yes	Yes	3	Not stated	
Eswatini	Yes	Yes	Yes	Yes	Yes	4	Not stated	
Lesotho	Yes		Yes	Yes	Yes	4	Over US$ 87 million	
Malawi	Yes	Yes	Yes	Yes	Yes	4	Not stated	
Mozambique	Yes	Yes	Yes	Yes	Yes	4	Not stated	Yes
Namibia	Yes	Yes	Yes	Yes		1	Not stated	
South Africa	Yes		Yes	Yes	Yes			
Zambia	Yes	Yes	Yes	Yes	Yes			
Zimbabwe	Yes	Yes	Yes	Yes	Yes			Yes

continued next page

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results, continued*

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY, *continued*

Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems, and school feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS***
Western Africa*	**12**	**15**	**10**	**9**	**12**	**3**	**3**	**7**
Benin	Yes	Yes	Yes		Yes			Yes
Burkina Faso	Yes	Yes		Yes	Yes			Yes
Cabo Verde		Yes						
Côte d'Ivoire		Yes		Yes	Yes	2	Not stated	
Gambia	Yes	Yes	Yes	Yes	Yes			
Ghana	Yes	Yes	Yes	Yes	Yes			Yes
Guinea	Yes	Yes	Yes	Yes				
Guinea-Bissau		Yes						
Liberia	Yes	Yes			Yes			
Mali	Yes	Yes	Yes	Yes	Yes	3	More than 50 billion FCFA	Yes
Niger	Yes	Yes	Yes	Yes	Yes			Yes
Nigeria	Yes	Yes	Yes		Yes			
Senegal	Yes	Yes	Yes	Yes	Yes			Yes
Sierra Leone	Yes	Yes	Yes		Yes			
Togo	Yes	Yes	Yes	Yes	Yes	4	Not stated	Yes

Note: * The items in this row are the number of countries in Africa of the sub-region corresponding to each indicator.
** This indicator is from level 2 of the CAADP Results Framework.
*** This refers to SAKSS platforms established between 2010 and 2017. Due to limited resources, the SAKSS platforms are not fully operational.
SAKSS = Strategic Analysis and Knowledge Support System.
NAIP = National Agriculture Investment Plan.
NAFSIP = National Agriculture and Food Security Investment Plan.

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results, continued

TABLE L 3(c)—PROGRESS IN BIENNIAL REVIEW PROCESS AS OF SEPTEMBER 2024

Country/Region	Inaugural Biennial Review process			Second Biennial Review process			Third Biennial Review process			Fourth Biennial Review process		
	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments
AFRICA*	**46**	**3.6**	**20**	**49**	**4.03**	**4**	**51**	**4.32**	**1**	**49**	**4.56**	
Central Africa*	**9**	**2.35**	**1**	**8**	**3.22**		**8**	**3.33**		**6**	**3.29**	
Burundi	Yes	4.71	On track	Yes	5.82		Yes	5.63		Yes	6.41	
Cameroon	Yes	2.14		Yes	4.21		Yes	4.58		Yes	3.7	
Central African Republic	Yes	2.4		Yes	4.41		Yes	2.61		Yes	1.73	
Chad	Yes	2.22		Yes	3.89		Yes	3.88				
Congo, Dem. Republic	Yes	1.44		Yes	3.33		Yes	4.46				
Congo, Rep. of	Yes	2.8		Yes	3.46		Yes	3.32		Yes	2.9	
Equatorial Guinea	Yes	3.61		Yes	2.46		Yes	2.82		Yes	3.3	
Gabon	Yes	2.86		Yes	3.99		Yes	4.98		Yes	4.79	
Sao Tome and Principe	Yes	1.54										
Eastern Africa*	**10**	**4.19**	**6**	**13**	**4**	**1**	**12**	**4.56**	**1**	**13**	**5**	
Comoros							Yes	1.5		Yes	3.2	
Djibouti	Yes	3.19		Yes	2.82		Yes	4		Yes	3.82	
Eritrea				Yes	3.89		Yes	3.17				
Ethiopia	Yes	5.35	On track	Yes	5.31		Yes	6.03		Yes	6	
Kenya	Yes	4.77	On track	Yes	4.88		Yes	5.62		Yes	6.28	
Madagascar	Yes	3.1		Yes	4.92		Yes	4.37		Yes	4.83	
Mauritius	Yes	5	On track	Yes	5.95					Yes	3.77	
Rwanda	Yes	6.09	On track	Yes	7.23	On track	Yes	7.43	On track	Yes	8.07	
Seychelles	Yes	4.01	On track	Yes	4.53		Yes	4.92		Yes	2.69	
Somalia				Yes	0.55					Yes	2.49	
South Sudan	Yes			Yes	2.89		Yes	4.05		Yes	3.51	
Sudan	Yes	1.91		Yes	3.33		Yes	3.32		Yes		
Tanzania	Yes	3.08		Yes	5.08		Yes	6.14		Yes	5.76	
Uganda	Yes	4.45	On track	Yes	5.68		Yes	5.89		Yes	6.77	

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results, continued

TABLE L 3(c)—PROGRESS IN BIENNIAL REVIEW PROCESS AS OF SEPTEMBER 2024, *continued*

Country/Region	Inaugural Biennial Review process			Second Biennial Review process			Third Biennial Review process			Fourth Biennial Review process		
	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments
Northern Africa*	**3**	**3.83**	**2**	**3**	**2.65**	**1**	**6**	**4.62**		**6**	**4.22**	
Algeria							Yes	1.47				
Egypt	Yes	3.37					Yes	6.52		Yes	6.83	
Libya							Yes	1.14		Yes	0.58	
Mauritania	Yes	4.78	On track	Yes	5.37		Yes	5.4		Yes	4.27	
Morocco	Yes	5.54	On track	Yes	6.96	On track	Yes	6.89		Yes	6.99	
Tunisia					6.2		Yes	6.28		Yes	6.23	
Southern Africa*	**10**	**4.02**	**6**	**10**	**4.27**		**10**	**4.11**		**10**	**4.26**	
Angola	Yes	2.1		Yes	4.77		Yes	3.77		Yes	1.43	
Botswana	Yes	4.38	On track	Yes	3.35		Yes	4.95		Yes	3.14	
Eswatini	Yes	3.74	On track	Yes	3.25		Yes	5.73		Yes	5.63	
Lesotho	Yes	4.92		Yes	4.81		Yes	3.98		Yes	4.16	
Malawi	Yes	4.13	On track	Yes	4.05		Yes	5.33		Yes	5.24	
Mozambique	Yes	4.11	On track	Yes	3.38		Yes	4.14		Yes	4.64	
Namibia	Yes	4.08	On track	Yes	2.88		Yes	4.08		Yes	4.26	
South Africa	Yes	4	On track	Yes	4.19		Yes	4.05		Yes	4.11	
Zambia	Yes	3.6		Yes	5.11		Yes	5.55		Yes	4.41	
Zimbabwe	Yes	3.2		Yes	4.58		Yes	5.17		Yes	5.45	
Western Africa*	**13**	**3.62**	**5**	**15**	**4.94**	**2**	**15**	**4.75**		**15**	**5.03**	
Benin	Yes	4.32	On track	Yes	5.76		Yes	4.78		Yes	6	
Burkina Faso	Yes	4.24	On track	Yes	5.31		Yes	5.2		Yes	5.73	
Cabo Verde	Yes	4.61	On track	Yes	4.82		Yes	4.55		Yes	5.09	
Côte d'Ivoire	Yes	3.51		Yes	4.79		Yes	4.62		Yes	3.96	
Gambia	Yes	3.13		Yes	4.95		Yes	5.56		Yes	5.79	
Ghana	Yes	3.91		Yes	6.67	On track	Yes	6.61		Yes	6.68	
Guinea	Yes	3.26		Yes	4.43		Yes	4.02		Yes	4.11	
Guinea-Bissau				Yes	2.49		Yes	2.18		Yes	2.74	

TABLE L 3(c)—PROGRESS IN BIENNIAL REVIEW PROCESS AS OF SEPTEMBER 2024, *continued*

Country/Region	Inaugural Biennial Review process			Second Biennial Review process			Third Biennial Review process			Fourth Biennial Review process		
	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments	BR report drafted, validated, and submitted to REC	BR Score (out of 10)	Country on track to meet Malabo Commitments
Western Africa* cont'd	**13**	**3.62**	**5**	**15**	**4.94**	**2**	**15**	**4.75**		**15**	**5.03**	
Liberia	Yes	0.95		Yes	3.05		Yes	3.93		Yes	3.46	
Mali	Yes	5.57	On track	Yes	6.82	On track	Yes	6.66		Yes	6.51	
Niger	Yes	3.52		Yes	4.11		Yes	3.64		Yes	4.32	
Nigeria	Yes	3.36		Yes	5.18		Yes	5.42		Yes	6.28	
Senegal	Yes	3.84		Yes	5.18		Yes	5.07		Yes	4.1	
Sierra Leone	Yes	1.53		Yes	5.34		Yes	4.33		Yes	5.9	
Togo	Yes	4.92	On track	Yes	5.14		Yes	4.67		Yes	4.8	

Source: Authors' compilation based on AUC (2018, 2020, 2022, and 2024).

Note: * The items in this row are the number of countries in the subregion corresponding to each indicator.

The BR benchmark scores (or the minimum score out of 10) required to be on track are 3.94 for the first BR, 6.66 for the second BR, 7.28 for the third BR, and 9.29 for the fourth BR.

ANNEX 4: Country Categories by Geographic Regions, Economic Classification, and Regional Economic Communities

TABLE 4.1—GEOGRAPHIC REGIONS

Western Africa	Eastern Africa	Southern Africa	Central Africa	Northern Africa
Benin	Comoros	Angola	Burundi	Algeria
Burkina Faso	Djibouti	Botswana	Cameroon	Egypt
Cabo Verde	Eritrea	Eswatini	Central African Republic	Libya
Côte d'Ivoire	Ethiopia	Lesotho	Chad	Mauritania
Gambia	Kenya	Malawi	Congo, Dem. Rep.	Morocco
Ghana	Madagascar	Mozambique	Congo, Rep.	Tunisia
Guinea	Mauritius	Namibia	Equatorial Guinea	
Guinea-Bissau	Rwanda	South Africa	Gabon	
Liberia	Seychelles	Zambia	Sao Tome and Principe	
Mali	Somalia	Zimbabwe		
Niger	South Sudan			
Nigeria	Sudan			
Senegal	Tanzania			
Sierra Leone	Uganda			
Togo				

ANNEX 4: Country Categories by Geographic Regions, Economic Classification, and Regional Economic Communities

TABLE 4.2—ECONOMIC CLASSIFICATIONS

Mineral-rich countries	Less favorable agriculture conditions	More favorable agriculture conditions	Lower middle-income countries	Upper middle-income countries
Central African Republic	Burundi	Benin	Algeria	Botswana
Congo, Dem. Rep.	Chad	Burkina Faso	Angola	Equatorial Guinea
Liberia	Eritrea	Ethiopia	Cabo Verde	Gabon
Sierra Leone	Mali	Gambia	Cameroon	Libya
South Sudan	Niger	Guinea-Bissau	Comoros	Mauritius
Sudan	Rwanda	Madagascar	Congo, Rep.	Namibia
	Somalia	Malawi	Côte d'Ivoire	Seychelles
		Mozambique	Djibouti	South Africa
		Tanzania	Egypt	
		Togo	Eswatini	
		Uganda	Ghana	
			Guinea	
			Kenya	
			Lesotho	
			Mauritania	
			Morocco	
			Nigeria	
			Sao Tome and Principe	
			Senegal	
			Tunisia	
			Zambia	
			Zimbabwe	

ANNEX 4: Country Categories by Geographic Regions, Economic Classification, and Regional Economic Communities

TABLE 4.3—REGIONAL ECONOMIC COMMUNITIES

CEN-SAD	COMESA	SADC	ECOWAS	ECCAS	IGAD	EAC	UMA
Benin	Burundi	Angola	Benin	Angola	Djibouti	Burundi	Algeria
Burkina Faso	Comoros	Botswana	Burkina Faso	Burundi	Eritrea	Congo, Dem. Rep.	Libya
Cabo Verde	Congo, Dem. Rep.	Comoros	Cabo Verde	Cameroon	Ethiopia	Kenya	Mauritania
Central African Republic	Djibouti	Congo, Dem. Rep.	Côte d'Ivoire	Central African Republic	Kenya	Rwanda	Morocco
Chad	Egypt	Eswatini	Gambia	Chad	Somalia	Tanzania	Tunisia
Comoros	Eritrea	Lesotho	Ghana	Congo, Dem. Rep.	South Sudan	South Sudan	
Côte d'Ivoire	Eswatini	Madagascar	Guinea	Congo, Rep.	Sudan	Uganda	
Djibouti	Ethiopia	Malawi	Guinea-Bissau	Equatorial Guinea	Uganda		
Egypt	Kenya	Mauritius	Liberia	Gabon			
Eritrea	Libya	Mozambique	Mali	Rwanda			
Gambia	Madagascar	Namibia	Niger	Sao Tome and Principe			
Ghana	Malawi	Seychelles	Nigeria				
Guinea	Mauritius	South Africa	Senegal				
Guinea-Bissau	Rwanda	Tanzania	Sierra Leone				
Kenya	Seychelles	Zambia	Togo				
Liberia	Somalia	Zimbabwe					
Libya	Sudan						
Mali	Tunisia						
Mauritania	Uganda						
Morocco	Zambia						
Niger	Zimbabwe						
Nigeria							
Sao Tome and Principe							
Senegal							
Sierra Leone							
Somalia							
Sudan							
Togo							
Tunisia							

Note: CEN-SAD = Community of Sahel-Saharan States; COMESA = Common Market for Eastern and Southern Africa; EAC = East African Community; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; IGAD = Intergovernmental Authority for Development; SADC = Southern African Development Community; UMA = Arab Maghreb Union.

ANNEX 5: *Distribution of Countries by Year of Signing CAADP Compact and Level of CAADP Implementation Reached by End of 2015*

TABLE 5.1—CAADP COMPACT SIGNING AND LEVEL OF CAADP IMPLEMENTATION

Period when CAADP compact was signed				Level or stage of CAADP implementation reached by end of 2015				
2007–2009	2010–2012	2013–2015	Not signed	LEVEL 0 Not started or pre-compact	LEVEL 1 Signed compact	LEVEL 2 Level 1 plus NAIP	LEVEL 3 Level 2 plus one external funding source	LEVEL 4 Level 3 plus other external funding source
CC1	CC2	CC3	CC0	CL0	CL1	CL2	CL3	CL4
Benin	Burkina Faso	Angola	Algeria	Algeria	Angola	Cameroon	Burundi	Benin
Burundi	Central Afr. Rep.	Cameroon	Comoros	Comoros	Chad	Cabo Verde	Gambia	Burkina Faso
Cabo Verde	Congo, Dem. Rep.	Chad	Egypt	Egypt	Congo, Rep.	Central Afr. Rep.	Liberia	Côte d'Ivoire
Ethiopia	Côte d'Ivoire	Congo, Rep.	Eritrea	Eritrea	Eswatini	Congo, Dem. Rep.	Mali	Ethiopia
Gambia	Djibouti	Eq. Guinea	Libya	Libya	Eq. Guinea	Djibouti	Niger	Ghana
Ghana	Eswatini	Gabon	Morocco	Morocco	Gabon	Guinea	Sierra Leone	Kenya
Liberia	Guinea	Lesotho	Somalia	Somalia	Lesotho	Guinea Bissau	Togo	Malawi
Mali	Guinea Bissau	Madagascar	South Africa	South Africa	Madagascar	Mauritania	Uganda	Mozambique
Niger	Kenya	Mauritius	South Sudan	South Sudan	Mauritius	Sao Tome and Principe	Zambia	Nigeria
Nigeria	Malawi	Sudan	Tunisia	Tunisia	Seychelles			Rwanda
Rwanda	Mauritania	Sao Tome and Principe			Sudan			Senegal
Sierra Leone	Mozambique	Zimbabwe			Zimbabwe			Tanzania
Togo	Senegal							
	Seychelles							
	Tanzania							
	Uganda							
	Zambia							
Count								
13	17	12	10	10	12	9	9	12
AgShare in GDP (%)								
26.0	20.2	14.6	7.6	7.6	14.1	18.8	26.2	24.1

Note: NAIP = national agriculture investment plan. There are three external funding sources considered—Grow Africa, New Alliance Cooperation, and the Global Agriculture and Food Security Program (GAFSP). AgShare in GDP is the average share of agricultural GDP in total GDP for 2003–2023.

ANNEX 6: Distribution of Countries in Formulating First-Generation Investment Plan (NAIP1.0) and Second-Generation Investment Plan (NAIP2.0) Reached by September of 2024

TABLE 6.1—PROGRESS IN NAIP FORMULATION

NAIP00	NAIP01	NAIP10	NAIP11	
Algeria	Botswana	Central African Republic	Benin	Mali
Angola	Chad	Congo, Dem. Republic	Burkina Faso	Mauritania
Equatorial Guinea	Comoros	Sao Tome and Principe	Burundi	Mozambique
Lesotho	Egypt		Cabo Verde	Niger
Somalia	Eritrea		Cameroon	Nigeria
South Africa	Gabon		Congo Rep.	Rwanda
	Libya		Côte d'Ivoire	Senegal
	Madagascar		Djibouti	Seychelles
	Mauritius		Eswatini	Sierra Leone
	Morocco		Ethiopia	South Sudan
	Namibia		Gambia	Sudan
	Tunisia		Ghana	Tanzania
			Guinea	Togo
			Guinea Bissau	Uganda
			Kenya	Zambia
			Liberia	Zimbabwe
			Malawi	
Count				
6	12	3	33	
AgShare in GDP (%)				
5.1	10.6	21.0	23.6	

Note: NAIP00 = countries that have neither NAIP1.0 nor NAIP2.0, NAIP01= countries that do not have a NAIP1.0 but have NAIP2.0, NAIP10 = countries that have a NAIP1.0 but do not have NAIP2.0, NAIP11 = countries that have both NAIP1.0 and NAIP2.0.

ANNEX 7a: Supplementary Data Tables

TABLE O.1.1A—AGRICULTURAL ODA (% total ODA)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	3.7	3.6	3.4	5.5	5.4	6.2	−3.7	5.0
Central	1.8	2.1	25.8	3.2	17.2	4.3	1.7	4.6
Eastern	4.7	4.3	−1.5	5.8	3.5	6.5	−4.2	5.0
Northern	3.6	3.6	−1.8	4.8	7.9	4.7	−13.4	1.9
Southern	2.9	3.4	3.5	5.5	6.4	5.9	−2.9	5.7
Western	5.1	4.0	−0.6	6.8	3.6	7.6	−1.3	7.1
Less favorable agriculture conditions	5.9	5.4	−1.0	7.1	5.3	7.7	−0.4	7.1
More favorable agriculture conditions	4.9	5.1	−2.1	6.8	3.6	7.5	−3.3	6.7
Mineral-rich countries	1.3	1.4	16.2	3.5	17.1	3.8	−3.5	3.5
Lower middle-income countries	3.9	3.3	3.8	5.5	3.4	6.1	−5.0	4.3
Upper middle-income countries	4.0	3.8	−12.8	2.0	2.2	1.6	−2.9	1.5
CEN-SAD	4.7	3.8	−1.9	5.7	4.7	6.1	−4.3	4.5
COMESA	3.2	3.4	7.2	5.2	7.2	6.1	−5.5	4.6
EAC	2.8	3.9	20.5	5.0	2.4	6.5	1.0	5.7
ECCAS	1.8	2.3	28.9	3.9	12.6	5.3	−0.1	5.1
ECOWAS	5.1	4.0	−0.6	6.8	3.6	7.6	−1.3	7.1
IGAD	4.4	4.0	−1.7	5.7	6.3	6.3	−4.1	4.9
SADC	2.6	3.3	12.0	4.7	3.6	5.3	−3.0	4.9
UMA	5.1	4.0	−11.2	4.8	7.8	4.3	0.5	3.5
CAADP Compact 2007-09 (CC1)	4.2	3.4	−2.8	6.7	7.3	7.8	−1.3	7.1
CAADP Compact 2010-12 (CC2)	3.7	4.5	12.6	5.4	1.2	6.5	−1.4	6.0
CAADP Compact 2013-15 (CC3)	3.8	2.8	−4.6	5.6	15.8	5.1	−8.1	3.8
CAADP Compact not yet (CC0)	3.3	3.2	−5.3	3.8	11.8	3.9	−11.7	1.8
CAADP Level 0 (CL0)	3.3	3.2	−5.3	3.8	11.8	3.9	−11.7	1.8
CAADP Level 1 (CL1)	3.8	3.0	−3.7	5.8	14.8	4.9	−9.4	3.4
CAADP Level 2 (CL2)	2.4	2.5	18.0	3.0	3.6	3.9	4.9	4.7
CAADP Level 3 (CL3)	4.2	4.5	2.2	6.9	8.2	7.7	0.9	7.4
CAADP Level 4 (CL4)	4.5	4.2	1.5	6.5	2.1	7.7	−3.0	6.6
NAIP00 (N00)	2.0	2.0	5.6	2.5	−0.1	2.3	5.7	2.4
NAIP01 (N01)	4.5	4.0	−5.1	4.9	8.2	4.9	−11.7	2.3
NAIP10 (N10)	0.9	1.7	54.5	2.7	8.9	2.9	0.3	3.5
NAIP11 (N11)	4.4	4.0	0.1	6.3	5.2	7.2	−2.8	6.2

Source: ReSAKSS based on OECD (2024) and World Bank (2024).
Note: ODA refers to gross disbursements.

ANNEX 7a: Supplementary Data Tables

TABLE O.1.1B—AGRICULTURAL ODA DISBURSEMENTS (as % of agricultural ODA commitments)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	81.1	76.1	−4.9	74.2	2.3	73.2	−2.7	60.2
Central	67.6	78.1	13.7	71.6	2.6	72.0	−1.6	55.5
Eastern	72.8	78.9	−1.5	78.4	2.4	77.0	−0.9	80.6
Northern	121.7	71.4	−18.6	65.3	16.8	136.8	5.1	160.7
Southern	85.4	88.5	−1.8	84.0	0.9	84.0	−5.0	72.9
Western	86.6	76.2	−7.7	75.6	−2.5	68.8	−3.7	52.4
Less favorable agriculture conditions	91.7	89.0	−8.0	74.6	3.3	74.0	1.8	66.4
More favorable agriculture conditions	81.3	87.5	−2.7	82.6	−1.8	71.6	−2.4	64.0
Mineral-rich countries	57.7	62.3	0.8	80.9	11.2	73.8	−7.1	57.6
Lower middle-income countries	88.3	65.6	−7.3	70.5	3.4	79.0	−4.2	56.0
Upper middle-income countries	85.8	120.8	5.8	105.9	14.6	109.8	−1.9	113.2
CEN-SAD	89.7	68.8	−8.6	70.6	4.2	72.7	−2.9	56.6
COMESA	77.4	79.0	−4.7	72.9	2.4	78.5	0.1	80.3
EAC	59.0	82.0	16.0	85.9	−0.3	77.1	0.5	75.2
ECCAS	70.3	77.2	7.8	73.5	2.2	74.8	−0.9	61.9
ECOWAS	86.6	76.2	−7.7	75.6	−2.5	68.8	−3.7	52.4
IGAD	67.5	75.3	−4.0	76.9	4.9	77.5	−1.0	90.8
SADC	81.1	87.3	2.8	86.9	−1.0	78.8	−4.2	61.9
UMA	99.4	77.2	−22.7	106.5	48.2	132.5	−1.9	143.4
CAADP Compact 2007-09 (CC1)	81.1	75.9	−11.6	75.4	−0.6	69.5	−2.3	53.7
CAADP Compact 2010-12 (CC2)	72.5	84.2	8.4	82.0	−1.3	76.3	−3.5	63.8
CAADP Compact 2013-15 (CC3)	94.2	82.0	−8.1	74.2	9.1	66.5	−3.8	58.0
CAADP Compact not yet (CC0)	125.9	87.5	−23.9	64.3	18.5	132.9	2.5	121.6
CAADP Level 0 (CL0)	125.9	87.5	−23.9	64.3	18.5	132.9	2.5	121.6
CAADP Level 1 (CL1)	84.1	77.8	−9.2	81.7	14.5	66.3	−5.2	54.7
CAADP Level 2 (CL2)	81.9	87.1	7.4	78.4	−7.7	66.7	−2.9	58.0
CAADP Level 3 (CL3)	78.5	100.8	−0.1	79.8	0.7	66.3	0.8	67.7
CAADP Level 4 (CL4)	77.5	70.4	−2.5	78.7	−2.0	76.8	−4.1	56.0
NAIP00 (N00)	76.6	86.4	3.7	95.1	−0.5	93.8	−5.4	98.4
NAIP01 (N01)	122.7	89.0	−19.9	65.6	14.4	99.6	−0.7	64.5
NAIP10 (N10)	57.3	66.7	6.4	83.7	7.7	76.5	−6.3	51.6
NAIP11 (N11)	76.5	75.8	−2.2	75.8	0.1	72.2	−2.8	60.0

Source: ReSAKSS based on OECD (2024) and World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.1.1C—EMERGENCY FOOD AID (% of total ODA)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014–2022)	2022
Africa	4.7	5.2	−0.3	5.1	−10.5	4.5	2.4	4.7
Central	1.8	3.2	26.1	4.8	0.3	6.2	3.6	6.2
Eastern	10.3	10.9	−9.2	9.2	−12.0	6.7	1.5	8.2
Northern	1.2	1.6	9.0	1.6	−15.2	1.2	5.9	1.4
Southern	4.5	4.3	7.5	3.1	−21.8	2.0	2.4	1.3
Western	1.0	0.9	−8.0	1.5	24.1	3.1	−0.5	2.4
Less favorable agriculture conditions	5.1	6.6	−3.9	9.6	−0.2	7.0	−3.6	5.7
More favorable agriculture conditions	6.4	6.3	−15.9	4.3	−13.4	4.4	5.7	5.8
Mineral-rich countries	5.5	8.0	14.6	7.4	−5.5	6.1	2.5	6.9
Lower middle-income countries	3.1	3.4	17.4	3.6	−17.9	2.9	1.7	2.3
Upper middle-income countries	0.2	0.1	−11.4	0.4	19.6	0.6	30.5	0.9
CEN-SAD	4.3	5.3	3.5	6.0	−8.0	4.8	−0.3	4.5
COMESA	7.4	9.5	4.2	8.7	−12.9	6.5	2.8	7.9
EAC	2.6	3.7	11.2	3.6	−7.1	3.3	1.5	3.2
ECCAS	3.6	3.3	4.8	4.1	0.1	5.1	3.7	5.1
ECOWAS	1.0	0.9	−8.0	1.5	24.1	3.1	−0.5	2.4
IGAD	14.4	15.4	−9.2	12.4	−12.4	8.7	0.1	10.4
SADC	2.6	2.9	16.8	2.8	−14.6	2.6	6.5	2.6
UMA	1.2	1.6	9.0	1.6	−15.2	1.2	5.9	1.4
CAADP Compact 2007-09 (CC1)	6.5	5.5	−14.7	4.7	−7.7	5.4	1.3	5.7
CAADP Compact 2010-12 (CC2)	1.8	2.5	11.9	2.8	−4.1	2.8	1.0	2.8
CAADP Compact 2013-15 (CC3)	12.0	12.2	5.6	13.7	−11.0	8.0	0.3	8.2
CAADP Compact not yet (CC0)	6.7	6.9	−14.6	5.9	−14.1	4.4	8.0	4.8
CAADP Level 0 (CL0)	6.7	6.9	−14.6	5.9	−14.1	4.4	8.0	4.8
CAADP Level 1 (CL1)	15.4	15.2	6.1	15.4	−10.8	8.9	0.1	9.1
CAADP Level 2 (CL2)	1.3	2.3	24.4	3.4	0.3	5.0	4.0	5.4
CAADP Level 3 (CL3)	3.5	3.3	−10.7	2.9	9.5	3.1	−5.4	2.4
CAADP Level 4 (CL4)	4.5	4.4	−9.7	3.9	−12.2	3.9	2.6	4.3
NAIP00 (N00)	9.6	7.1	−6.7	8.8	−7.2	7.5	5.0	7.9
NAIP01 (N01)	4.9	4.6	−22.1	3.5	−17.3	2.6	10.6	3.1
NAIP10 (N10)	1.6	3.6	45.0	4.5	−1.6	6.7	6.8	7.5
NAIP11 (N11)	5.2	5.6	−3.2	5.1	−11.0	4.3	0.9	4.5

Source: ReSAKSS based on OECD (2024) and World Bank (2024).
Note: ODA and food aid refer to gross disbursements.

ANNEX 7a: Supplementary Data Tables

TABLE O.1.2A—GENERAL GOVERNMENT GROSS DEBT (% of GDP)										
Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	49.8	−2.9	42.2	29.6	−14.9	21.6	2.1	35.8	5.6	39.9
Central	83.7	1.4	79.7	52.3	−18.8	20.8	−9.0	25.3	1.4	24.3
Eastern	79.7	−5.6	64.3	43.4	−18.3	37.4	7.0	58.8	4.9	64.9
Northern	44.2	−6.2	36.1	26.0	−14.9	16.4	0.0	27.3	7.6	32.3
Southern	38.5	−3.4	31.0	25.0	−4.4	28.9	6.1	48.3	3.5	48.8
Western	47.3	2.9	43.0	27.4	−20.7	14.1	−2.9	25.6	8.5	31.8
Less favorable agriculture conditions	73.6	−2.4	60.7	39.3	−20.8	26.0	6.6	38.9	1.7	38.4
More favorable agriculture conditions	68.7	−5.3	58.7	40.0	−21.7	25.1	5.3	39.9	2.8	40.2
Mineral-rich countries	133.0	−0.4	120.6	80.8	−17.9	46.9	−2.2	71.5	7.2	79.8
Lower middle-income countries	47.5	−3.9	38.8	26.3	−17.0	16.3	−0.4	29.8	7.9	35.4
Upper middle-income countries	25.3	−0.1	22.4	20.2	2.7	30.0	9.0	44.4	1.8	45.1
CEN-SAD	49.6	−1.6	44.3	31.6	−15.3	20.7	0.2	35.8	7.7	42.9
COMESA	57.3	−2.9	54.1	40.2	−14.4	27.6	0.6	45.1	7.0	53.2
EAC	54.1	1.3	56.1	40.9	−14.8	27.3	−1.4	42.6	6.7	54.5
ECCAS	88.4	−3.8	68.9	42.9	−21.1	20.3	−3.8	36.1	5.8	35.4
ECOWAS	47.3	2.9	43.0	27.4	−20.7	14.1	−2.9	25.6	8.5	31.8
IGAD	85.1	−5.1	70.0	47.2	−17.9	38.4	5.8	60.7	5.2	66.9
SADC	43.0	−2.3	36.5	28.6	−7.2	29.8	4.8	46.7	3.1	47.1
UMA	52.6	−6.6	37.9	24.1	−17.8	17.8	4.4	26.3	3.8	28.4
CAADP Compact 2007-09 (CC1)	40.0	6.0	40.0	24.0	−25.6	11.7	2.0	24.9	8.2	29.8
CAADP Compact 2010-12 (CC2)	76.3	−1.5	68.4	48.8	−14.7	32.3	−2.2	46.9	3.9	49.7
CAADP Compact 2013-15 (CC3)	97.2	−7.2	69.1	45.3	−17.9	34.2	3.5	63.2	8.7	74.7
CAADP Compact not yet (CC0)	35.5	−4.4	29.9	23.5	−8.4	21.1	4.2	32.5	4.2	35.3
CAADP Level 0 (CL0)	35.5	−4.4	29.9	23.5	−8.4	21.1	4.2	32.5	4.2	35.3
CAADP Level 1 (CL1)	99.5	−7.0	71.5	47.5	−17.1	37.4	3.6	69.4	9.0	82.6
CAADP Level 2 (CL2)	79.5	5.2	85.1	60.2	−16.1	26.9	−11.2	25.5	0.2	23.3
CAADP Level 3 (CL3)	96.4	1.3	90.8	55.1	−25.0	22.8	−0.7	43.1	5.4	44.4
CAADP Level 4 (CL4)	46.8	−0.3	41.0	26.5	−20.2	16.6	1.6	31.7	7.1	37.3
NAIP00 (N00)	39.1	−6.2	27.6	19.2	−9.9	20.2	7.0	31.5	2.3	30.5
NAIP01 (N01)	40.1	−4.4	36.7	29.8	−10.4	22.9	2.2	37.4	6.6	43.4
NAIP10 (N10)	78.6	14.6	105.4	79.3	−13.4	35.4	−14.5	25.0	−3.4	19.3
NAIP11 (N11)	62.9	−1.6	53.9	35.2	−19.4	21.4	0.4	37.7	6.9	43.9

Source: ReSAKSS based on AfDB (2024) and World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.1.2B—GENERAL GOVERNMENT GROSS REVENUE (% OF GDP)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	22.1	2.4	23.8	25.9	2.3	23.3	–3.9	18.4	–0.1	18.7
Central	16.1	4.6	19.1	24.4	8.6	21.7	–0.5	16.9	–1.3	18.1
Eastern	15.0	3.0	17.5	18.8	1.0	17.2	–2.6	14.3	–1.7	13.6
Northern	27.8	0.8	29.4	32.9	3.8	31.2	–2.7	25.3	0.7	26.1
Southern	24.2	0.8	23.6	25.9	3.6	28.8	0.6	26.3	–0.5	26.9
Western	16.1	8.6	19.8	20.1	–2.9	12.0	–15.6	6.9	1.1	7.2
Less favorable agriculture conditions	16.5	1.2	18.9	22.5	5.9	19.3	–2.5	17.5	2.3	19.0
More favorable agriculture conditions	15.6	2.7	17.7	18.7	2.1	17.1	–3.9	14.9	–1.2	14.2
Mineral-rich countries	9.6	5.2	12.7	15.2	3.7	16.4	2.2	13.4	–1.4	13.9
Lower middle-income countries	22.1	3.1	23.8	25.3	0.7	21.5	–5.3	16.0	–1.0	15.4
Upper middle-income countries	27.0	1.0	28.4	32.6	5.4	32.8	–1.2	30.1	2.6	34.9
CEN-SAD	20.5	2.8	22.7	24.5	1.6	19.8	–7.3	14.6	1.8	16.0
COMESA	22.3	0.3	23.9	26.6	3.3	24.6	–3.6	20.1	1.6	22.5
EAC	14.7	2.6	17.1	17.9	0.6	18.1	1.8	16.3	–1.0	17.0
ECCAS	21.2	4.3	22.5	28.5	9.0	28.9	–1.9	19.4	–0.8	20.4
ECOWAS	16.1	8.6	19.8	20.1	–2.9	12.0	–15.6	6.9	1.1	7.2
IGAD	15.0	3.2	17.7	19.0	1.0	17.3	–3.2	13.2	–3.0	11.7
SADC	22.2	1.2	22.2	24.3	3.5	26.7	0.5	24.3	–0.6	24.9
UMA	31.1	2.0	34.3	39.6	5.3	37.0	–2.9	29.8	3.2	33.5
CAADP Compact 2007-09 (CC1)	16.1	10.3	20.3	20.5	–3.2	12.0	–16.1	6.5	–0.6	6.1
CAADP Compact 2010-12 (CC2)	16.3	1.2	17.7	18.6	1.6	17.8	–1.0	16.9	0.0	17.6
CAADP Compact 2013-15 (CC3)	19.7	3.6	21.1	25.9	6.5	25.8	–2.1	17.9	–0.1	19.0
CAADP Compact not yet (CC0)	26.3	0.8	27.3	30.1	3.5	30.2	–1.3	26.1	0.0	26.6
CAADP Level 0 (CL0)	26.3	0.8	27.3	30.1	3.5	30.2	–1.3	26.1	0.0	26.6
CAADP Level 1 (CL1)	20.7	2.9	21.8	25.8	5.2	27.1	–2.1	18.6	0.1	19.9
CAADP Level 2 (CL2)	11.0	6.2	13.8	19.5	10.5	15.9	2.5	15.4	–1.1	16.3
CAADP Level 3 (CL3)	17.0	1.1	18.4	20.1	3.1	16.5	–2.0	17.1	1.3	17.5
CAADP Level 4 (CL4)	16.6	7.2	20.0	20.1	–2.7	13.4	–11.9	8.8	0.1	8.9
NAIP00 (N00)	26.8	1.8	27.6	30.6	3.4	31.7	–0.6	27.4	–1.0	26.4
NAIP01 (N01)	26.0	0.0	26.8	29.9	4.2	28.8	–2.9	23.7	1.7	26.1
NAIP10 (N10)	7.7	2.1	10.1	13.6	10.8	16.8	3.5	15.9	–1.3	17.8
NAIP11 (N11)	16.1	6.4	19.3	20.2	–1.0	14.4	–8.6	10.3	–0.1	10.4

Source: ReSAKSS based on AfDB (2024) and World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.1.3—ANNUAL INFLATION, GDP DEFLATOR (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	11.1	−2.4	9.6	10.3	0.7	8.5	−0.7	11.3	1.7	19.1
Central	5.1	−0.6	3.1	8.9	2.4	4.1	−1.9	2.0	−0.1	5.1
Eastern	13.9	−3.7	7.8	10.8	1.2	14.1	−0.3	18.5	2.1	29.7
Northern	7.5	−0.9	7.9	9.7	1.2	8.3	−1.0	9.0	1.1	14.6
Southern	9.2	−0.7	8.9	7.0	0.3	6.9	−0.3	16.0	4.1	32.0
Western	17.9	−5.8	14.4	13.8	−0.1	8.1	−0.5	8.2	0.7	11.9
Less favorable agriculture conditions	8.0	−1.9	3.5	6.9	1.5	4.4	−1.0	3.5	0.3	7.4
More favorable agriculture conditions	10.6	−2.3	8.0	8.8	1.6	11.9	−1.2	9.0	0.9	15.6
Mineral-rich countries	23.8	−7.9	12.7	13.6	−0.3	16.9	1.6	48.5	7.6	79.5
Lower middle-income countries	11.2	−3.0	9.5	10.7	0.5	8.5	−0.6	11.6	2.1	21.0
Upper middle-income countries	9.2	−0.3	10.2	9.4	0.8	6.2	−1.0	5.3	−0.2	5.3
CEN-SAD	12.4	−3.2	10.8	11.5	0.6	9.0	−0.5	11.2	1.1	16.0
COMESA	9.4	−1.4	9.6	10.9	1.1	11.9	−0.5	20.5	3.7	36.3
EAC	10.4	−1.0	6.1	9.5	1.2	12.0	−1.1	5.3	0.0	5.8
ECCAS	5.4	−0.7	3.4	9.1	2.2	4.2	−1.8	2.4	0.0	6.1
ECOWAS	17.9	−5.8	14.4	13.8	−0.1	8.1	−0.5	8.2	0.7	11.9
IGAD	14.7	−4.0	7.9	11.5	1.1	16.1	0.0	23.6	2.9	38.7
SADC	9.4	−0.9	8.7	7.2	0.4	7.1	−0.4	14.1	3.3	27.3
UMA	9.0	−1.1	8.4	9.8	1.2	5.1	−1.8	4.1	0.1	8.1
CAADP Compact 2007-09 (CC1)	18.8	−6.4	15.6	15.2	0.0	9.4	−0.6	10.1	1.0	16.1
CAADP Compact 2010-12 (CC2)	11.1	−1.3	6.8	8.0	1.0	8.9	−0.9	5.0	0.1	5.6
CAADP Compact 2013-15 (CC3)	11.1	−1.3	6.8	8.0	1.0	8.9	−0.9	5.0	0.1	5.6
CAADP Compact not yet (CC0)	7.9	−0.8	8.0	8.6	0.9	7.6	−0.8	7.8	0.7	11.3
CAADP Level 0 (CL0)	7.9	−0.8	8.0	8.6	0.9	7.6	−0.8	7.8	0.7	11.3
CAADP Level 1 (CL1)	13.4	−4.5	8.6	11.2	1.1	12.2	0.2	62.3	17.9	136.2
CAADP Level 2 (CL2)	3.9	−0.3	3.6	6.3	0.6	4.3	−1.0	3.1	0.3	5.1
CAADP Level 3 (CL3)	9.9	−1.2	7.8	8.2	0.6	10.3	−0.8	5.5	0.4	7.2
CAADP Level 4 (CL4)	17.2	−5.1	13.5	13.4	0.3	9.2	−0.6	8.9	0.7	13.4
NAIP00 (N00)	9.7	−5.5	7.9	8.2	5.1	6.5	−0.9	5.1	0.0	7.6
NAIP01 (N01)	6.2	−5.5	7.8	9.2	6.9	8.2	−0.8	9.5	0.9	12.7
NAIP10 (N10)	7.1	−5.1	4.6	6.2	15.9	7.4	−0.8	3.7	−0.5	4.7
NAIP11 (N11)	15.8	−12.0	12.1	12.4	−1.8	9.9	−0.5	15.0	2.6	26.5

Source: ReSAKSS based on World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.2.1A—AGRICULTURAL EXPORTS (% of total merchandise exports)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	13.0	−5.3	10.7	8.6	−7.1	9.3	2.9	12.4	0.2	12.0
Central	6.1	−10.9	4.1	3.5	−5.5	4.3	−3.7	3.2	0.5	3.6
Eastern	58.5	−2.9	49.4	45.4	−2.3	43.1	−2.9	42.1	−0.1	42.1
Northern	5.7	−5.1	4.9	4.7	−0.3	6.5	6.0	10.5	0.1	9.8
Southern	11.6	−1.9	10.6	7.9	−10.1	8.0	4.0	9.4	−0.2	9.5
Western	18.5	−9.0	13.9	10.5	−8.7	10.0	−1.4	14.5	−0.2	13.1
Less favorable agriculture conditions	19.3	−5.6	13.3	9.2	−0.8	14.1	−2.1	13.4	0.1	12.7
More favorable agriculture conditions	50.9	−3.0	43.5	41.5	−0.9	37.9	−2.2	33.5	−2.3	31.7
Mineral-rich countries	19.7	3.4	20.4	13.6	−19.2	10.2	−1.1	10.7	−1.0	8.7
Lower middle-income countries	13.7	−6.8	11.1	8.7	−8.2	8.8	1.5	12.4	1.2	12.3
Upper middle-income countries	7.4	−2.3	6.1	4.8	−6.0	6.3	7.3	8.7	−1.0	8.1
CEN-SAD	16.8	−6.8	12.7	10.1	−7.1	10.6	2.0	15.8	−0.6	14.1
COMESA	20.9	−4.3	15.0	12.1	−6.4	14.7	6.9	18.7	−2.0	17.6
EAC	42.1	−0.3	37.0	33.9	−2.6	31.5	−1.6	27.1	2.0	41.3
ECCAS	3.5	−11.1	2.4	1.9	−10.2	2.2	−0.2	2.2	2.5	2.6
ECOWAS	18.5	−9.0	13.9	10.5	−8.7	10.0	−1.4	14.5	−0.2	13.1
IGAD	69.1	−2.9	56.4	52.4	−2.0	49.1	−4.9	46.6	0.6	48.8
SADC	13.0	−1.9	12.2	9.5	−9.7	9.5	3.6	10.3	−0.9	10.2
UMA	5.0	−8.0	3.5	3.3	−0.2	4.4	8.9	8.4	0.4	7.6
CAADP Compact 2007-09 (CC1)	11.6	−8.9	9.1	7.2	−7.9	7.4	−0.7	10.1	0.5	9.2
CAADP Compact 2010-12 (CC2)	43.0	−1.0	39.1	34.3	−4.5	31.3	−1.8	27.4	−3.1	25.9
CAADP Compact 2013-15 (CC3)	12.0	−5.2	9.5	5.9	−16.8	4.5	5.1	7.8	3.3	7.4
CAADP Compact not yet (CC0)	7.3	−3.1	6.5	5.6	−3.2	7.5	5.2	10.5	0.1	10.2
CAADP Level 0 (CL0)	7.3	−3.1	6.5	5.6	−3.2	7.5	5.2	10.5	0.1	10.2
CAADP Level 1 (CL1)	12.4	−4.8	9.7	6.1	−16.7	4.6	6.2	8.0	3.8	7.7
CAADP Level 2 (CL2)	16.7	−2.9	16.3	14.3	−7.4	15.5	−2.5	11.9	−3.0	11.8
CAADP Level 3 (CL3)	19.3	3.0	22.2	21.9	−0.7	18.5	−5.6	17.5	0.1	19.4
CAADP Level 4 (CL4)	51.3	−1.8	48.3	44.4	−3.0	39.6	−3.5	36.3	−2.6	32.1
NAIP00 (N00)	5.3	−4.2	4.5	3.3	−8.0	4.5	7.5	6.4	1.3	6.7
NAIP01 (N01)	8.9	−2.2	7.8	7.1	−2.4	8.8	4.7	12.8	−0.2	12.0
NAIP10 (N10)	17.8	0.4	15.8	14.1	−2.9	17.1	−2.3	7.2	−6.2	6.6
NAIP11 (N11)	26.2	−8.2	19.3	15.6	−6.1	14.6	−0.7	19.2	−0.2	17.8

Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

ANNEX 7a: *Supplementary Data Tables*

TABLE O.2.1B—AGRICULTURAL IMPORTS (% of total merchandise imports)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	15.9	−0.8	15.4	13.9	−3.1	14.4	1.0	15.2	1.3	15.4
Central	17.5	−1.7	17.4	17.5	−2.1	15.1	−2.2	16.6	4.6	18.7
Eastern	15.0	−0.1	14.7	13.1	−3.6	14.4	0.8	16.1	2.3	16.5
Northern	20.4	−2.5	18.3	16.3	−2.1	16.5	2.0	17.8	1.6	19.0
Southern	9.8	1.0	10.2	9.0	−4.5	9.8	0.0	10.3	−0.5	9.1
Western	16.7	2.1	17.6	15.8	−4.1	16.2	1.5	15.9	−0.6	15.0
Less favorable agriculture conditions	22.1	−0.3	21.3	21.5	−3.0	21.5	−1.2	20.8	0.8	20.7
More favorable agriculture conditions	15.9	−1.7	15.9	14.0	−6.2	12.2	−1.7	13.9	2.3	14.1
Mineral-rich countries	15.9	−0.6	15.5	14.0	−1.5	16.4	2.7	17.7	−0.9	15.8
Lower middle-income countries	18.6	−0.9	17.9	15.9	−2.9	16.2	1.3	16.5	1.1	17.0
Upper middle-income countries	9.3	−1.4	9.0	8.0	−3.5	9.1	2.6	11.2	2.0	11.5
CEN-SAD	17.3	−0.6	16.7	15.1	−2.5	16.1	2.0	16.7	0.7	16.9
COMESA	16.9	−0.7	16.9	15.2	−2.4	16.4	1.8	17.7	2.5	20.4
EAC	14.6	−3.7	13.3	12.8	−2.3	13.1	0.0	13.0	0.3	12.9
ECCAS	20.4	−1.1	19.5	18.0	−3.7	15.9	−0.7	17.4	3.6	18.5
ECOWAS	16.7	2.1	17.6	15.8	−4.1	16.2	1.5	15.9	−0.6	15.0
IGAD	14.7	0.5	14.2	12.6	−3.9	14.6	0.5	16.6	3.1	17.6
SADC	10.8	0.2	11.3	10.2	−4.1	10.8	0.2	11.0	−0.5	9.8
UMA	19.8	−3.8	16.6	14.8	−1.4	14.7	1.5	17.0	2.1	18.2
CAADP Compact 2007-09 (CC1)	14.9	3.5	16.1	14.2	−5.4	14.5	1.7	14.4	0.9	14.6
CAADP Compact 2010-12 (CC2)	17.3	−1.1	16.7	15.4	−2.8	14.7	−2.0	15.0	0.3	14.4
CAADP Compact 2013-15 (CC3)	16.8	1.1	17.6	15.9	−2.6	16.6	1.5	19.2	2.9	19.8
CAADP Compact not yet (CC0)	15.4	−2.2	14.3	13.0	−2.3	13.8	1.4	14.8	1.5	15.3
CAADP Level 0 (CL0)	15.4	−2.2	14.3	13.0	−2.3	13.8	1.4	14.8	1.5	15.3
CAADP Level 1 (CL1)	17.0	1.1	17.7	15.9	−2.9	16.5	1.9	19.1	2.7	19.3
CAADP Level 2 (CL2)	22.2	−1.3	21.9	21.7	0.0	21.2	−2.5	19.9	0.3	20.2
CAADP Level 3 (CL3)	14.0	1.0	15.1	13.7	−3.9	12.4	−0.8	13.8	2.1	14.3
CAADP Level 4 (CL4)	15.6	1.3	15.8	14.0	−4.8	14.2	0.4	14.1	0.5	13.9
NAIP00 (N00)	14.4	−2.4	13.1	11.5	−4.0	12.1	1.1	13.5	0.9	12.8
NAIP01 (N01)	17.6	−1.4	16.7	15.2	−1.9	15.7	1.6	16.5	1.6	17.6
NAIP10 (N10)	21.6	−1.0	21.7	21.1	−0.2	20.7	0.4	16.6	−2.6	14.9
NAIP11 (N11)	15.2	1.7	16.0	14.2	−4.2	14.6	0.6	15.2	0.9	15.0

Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

TABLE O.2.2—RATIO OF AGRICULTURAL EXPORTS TO AGRICULTURAL IMPORTS

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	0.8	–1.7	0.8	0.7	–5.6	0.6	–1.0	0.7	0.9	0.7
Central	0.6	–8.7	0.4	0.4	–4.2	0.4	–7.3	0.3	–1.1	0.2
Eastern	1.7	–4.5	1.4	1.3	–4.8	1.1	–1.1	1.1	0.4	1.1
Northern	0.3	3.1	0.3	0.4	0.6	0.3	–3.2	0.4	2.7	0.4
Southern	1.3	–2.9	1.1	0.9	–3.8	0.9	3.0	1.0	2.4	1.2
Western	1.3	–7.2	1.2	1.0	–9.2	0.8	–2.7	0.9	–0.4	0.9
Less favorable agriculture conditions	0.4	–6.1	0.3	0.3	3.8	0.4	–1.0	0.4	1.5	0.4
More favorable agriculture conditions	1.5	–3.5	1.3	1.2	1.9	1.3	0.3	1.2	–1.8	1.1
Mineral-rich countries	0.8	–6.5	0.6	0.4	–13.4	0.5	2.7	0.6	5.8	0.6
Lower middle-income countries	0.7	–1.6	0.7	0.6	–7.7	0.5	–2.2	0.6	1.4	0.6
Upper middle-income countries	1.0	1.6	0.9	0.9	–2.6	0.8	–0.6	0.8	–0.6	0.8
CEN-SAD	0.8	–1.8	0.8	0.7	–7.9	0.6	–3.2	0.7	0.8	0.7
COMESA	0.8	–1.1	0.7	0.7	–5.1	0.6	–1.5	0.6	0.9	0.7
EAC	1.9	–0.7	1.7	1.5	–6.5	1.2	–3.4	1.2	1.3	1.4
ECCAS	0.3	–11.0	0.2	0.2	–1.5	0.2	–4.2	0.2	2.5	0.2
ECOWAS	1.3	–7.2	1.2	1.0	–9.2	0.8	–2.7	0.9	–0.4	0.9
IGAD	1.8	–6.0	1.4	1.3	–3.4	1.1	–1.7	1.1	1.3	1.2
SADC	1.3	–2.5	1.1	0.9	–4.7	0.9	2.7	1.0	1.6	1.1
UMA	0.3	0.4	0.3	0.4	3.3	0.3	–2.0	0.4	2.3	0.4
CAADP Compact 2007-09 (CC1)	0.9	–7.7	0.8	0.7	–7.3	0.6	–2.4	0.6	–0.5	0.6
CAADP Compact 2010-12 (CC2)	2.1	–2.1	1.8	1.6	–5.6	1.4	–1.6	1.4	–0.7	1.4
CAADP Compact 2013-15 (CC3)	0.9	–5.3	0.7	0.5	–9.9	0.4	0.2	0.5	2.5	0.5
CAADP Compact not yet (CC0)	0.4	2.8	0.5	0.5	–2.4	0.5	–0.5	0.6	1.7	0.6
CAADP Level 0 (CL0)	0.4	2.8	0.5	0.5	–2.4	0.5	–0.5	0.6	1.7	0.6
CAADP Level 1 (CL1)	0.9	–4.5	0.7	0.6	–9.2	0.4	1.3	0.5	3.4	0.5
CAADP Level 2 (CL2)	0.9	–7.8	0.6	0.6	–6.5	0.6	–2.2	0.6	1.7	0.6
CAADP Level 3 (CL3)	0.9	–2.6	0.9	0.9	3.8	0.9	–2.1	0.8	–0.4	0.9
CAADP Level 4 (CL4)	1.7	–7.7	1.5	1.2	–6.4	1.0	–2.2	1.1	–1.1	1.0
NAIP00 (N00)	0.5	1.1	0.4	0.4	–2.6	0.5	3.8	0.5	3.6	0.7
NAIP01 (N01)	0.4	2.2	0.5	0.5	–2.4	0.4	–2.8	0.5	1.2	0.5
NAIP10 (N10)	0.9	–3.4	0.7	0.6	–4.0	0.8	–0.8	0.6	–0.5	0.5
NAIP11 (N11)	1.6	–6.5	1.4	1.1	–6.2	0.9	–2.7	1.0	–0.1	1.0

Source: ReSAKSS based on UNCTAD (2024) and World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.3.1—TOTAL FERTILIZER CONSUMPTION (kilograms per hectare)										
Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014–2022)	2022
Africa	20.6	1.1	22.2	22.8	1.2	24.7	4.4	31.8	3.6	35.3
Central	5.1	4.8	5.3	4.6	–3.8	5.1	5.9	8.1	5.7	9.3
Eastern	9.1	–1.8	8.5	9.2	8.1	13.4	4.6	18.0	5.2	20.8
Northern	71.8	2.5	82.9	87.7	0.6	88.2	4.6	98.1	–1.1	96.3
Southern	35.6	0.3	37.0	36.2	1.8	39.5	3.5	54.0	7.7	69.1
Western	7.5	1.0	7.8	7.8	–2.9	9.0	8.5	16.5	8.0	19.0
Less favorable agriculture conditions	2.3	4.6	2.8	3.0	7.0	3.1	3.3	6.9	8.2	8.9
More favorable agriculture conditions	8.7	–3.3	7.8	8.3	9.4	12.4	5.6	19.6	9.1	26.6
Mineral-rich countries	4.7	–0.3	6.1	6.3	4.8	9.0	0.0	12.7	3.8	12.9
Lower middle-income countries	28.8	2.6	32.2	33.1	–0.6	34.4	5.2	42.5	1.3	43.9
Upper middle-income countries	52.7	–0.9	53.4	51.8	1.3	55.3	3.5	72.0	7.3	89.2
CEN-SAD	21.9	1.8	24.3	25.8	0.4	26.2	3.5	31.5	1.7	32.6
COMESA	33.5	0.2	35.4	38.1	2.4	41.1	3.1	49.9	2.3	55.3
EAC	7.7	2.6	8.6	10.2	5.1	14.8	10.3	20.1	4.9	22.1
ECCAS	4.4	4.3	4.7	4.5	1.8	5.6	6.0	8.6	5.5	9.8
ECOWAS	7.5	1.0	7.8	7.8	–2.9	9.0	8.5	16.5	8.0	19.0
IGAD	10.1	–1.3	9.2	10.0	10.3	14.9	3.1	19.7	6.1	24.0
SADC	26.9	–0.2	27.8	27.1	1.4	30.4	4.3	42.2	7.3	52.6
UMA	29.2	5.6	35.9	36.1	1.0	39.4	6.2	39.9	–2.5	36.4
CAADP Compact 2007-09 (CC1)	6.8	–1.9	5.9	6.7	8.6	9.3	5.6	17.0	10.3	21.4
CAADP Compact 2010-12 (CC2)	11.5	1.9	13.4	13.4	0.2	16.7	8.5	25.2	5.9	30.6
CAADP Compact 2013-15 (CC3)	11.5	1.9	13.4	13.4	0.2	16.7	8.5	25.2	5.9	30.6
CAADP Compact not yet (CC0)	64.2	1.7	73.4	75.6	0.7	75.3	3.8	88.2	1.6	94.3
CAADP Level 0 (CL0)	64.2	1.7	73.4	75.6	0.7	75.3	3.8	88.2	1.6	94.3
CAADP Level 1 (CL1)	9.0	–0.5	7.8	7.1	–2.1	8.5	–2.8	9.9	1.5	9.2
CAADP Level 2 (CL2)	4.4	6.5	5.6	5.0	–3.4	5.7	7.8	8.8	6.1	9.9
CAADP Level 3 (CL3)	4.2	2.4	5.7	6.0	5.0	7.2	5.4	11.8	3.9	12.6
CAADP Level 4 (CL4)	10.7	–0.1	10.6	11.2	3.3	14.8	7.5	24.3	8.6	30.7
NAIP00 (N00)	33.8	0.5	36.5	35.0	1.1	38.0	5.0	50.5	6.2	61.1
NAIP01 (N01)	73.6	2.3	84.2	90.2	0.8	87.9	3.5	95.5	–1.5	91.9
NAIP10 (N10)	2.7	6.7	3.8	3.9	6.0	4.7	3.4	5.2	–0.4	4.9
NAIP11 (N11)	9.0	0.4	9.1	9.3	2.2	11.8	5.5	18.7	7.6	22.6

Source: ReSAKSS based on World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.3.2—AGRICULTURAL VALUE ADDED (% GDP)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	17.8	−1.6	16.9	15.2	−3.3	14.5	−1.2	14.9	1.0	15.3
Central	24.1	−5.7	18.5	16.0	−5.7	14.6	−1.0	15.5	0.8	15.3
Eastern	32.7	−2.3	29.1	28.1	−1.6	26.2	−0.5	24.6	−0.8	23.7
Northern	13.7	−4.5	11.2	9.9	−4.6	9.8	0.9	10.5	0.2	10.4
Southern	5.5	−1.9	5.0	4.6	−1.7	4.5	−0.7	5.2	2.6	6.0
Western	27.3	1.9	30.8	26.5	−4.2	23.2	−4.0	22.1	1.4	23.0
Less favorable agriculture conditions	34.8	−1.2	32.4	31.2	−0.7	30.6	0.4	32.2	0.4	33.2
More favorable agriculture conditions	32.3	−4.0	28.0	28.5	1.0	30.6	−0.9	28.1	−0.1	28.1
Mineral-rich countries	36.5	−2.4	31.5	28.9	−3.2	23.5	−2.0	18.8	−5.0	14.5
Lower middle-income countries	19.1	−1.0	19.2	16.9	−4.4	15.3	−2.2	15.5	1.3	16.1
Upper middle-income countries	3.4	−1.9	3.2	2.6	−5.6	2.3	−1.1	2.7	0.4	2.7
CEN-SAD	22.5	−0.2	22.4	19.8	−3.7	18.0	−2.4	17.1	0.0	16.9
COMESA	22.2	−3.5	18.2	17.1	−2.0	16.3	−1.0	15.4	−0.2	15.5
EAC	31.3	−4.2	25.7	23.5	−4.5	21.1	0.3	22.5	0.9	23.0
ECCAS	18.9	−6.1	14.3	12.3	−6.3	11.5	0.5	14.0	2.7	15.6
ECOWAS	27.3	1.9	30.8	26.5	−4.2	23.2	−4.0	22.1	1.4	23.0
IGAD	35.4	−2.2	31.2	30.0	−1.6	27.5	−0.5	25.4	−0.8	24.6
SADC	9.0	−4.1	7.6	7.2	−1.8	7.2	−0.2	8.2	2.1	8.9
UMA	12.0	−7.8	8.5	7.3	−6.6	7.9	5.0	10.1	0.9	10.1
CAADP Compact 2007-09 (CC1)	30.4	1.4	33.4	29.0	−3.7	25.6	−3.8	24.3	1.7	25.8
CAADP Compact 2010-12 (CC2)	25.4	−3.2	22.3	20.9	−2.5	20.3	−1.4	19.7	−0.1	19.1
CAADP Compact 2013-15 (CC3)	20.6	−1.0	19.0	17.4	−3.6	14.4	−3.3	13.0	−1.9	12.4
CAADP Compact not yet (CC0)	9.1	−1.7	8.2	7.3	−4.1	7.2	0.5	8.0	1.0	8.1
CAADP Level 0 (CL0)	9.1	−1.7	8.2	7.3	−4.1	7.2	0.5	8.0	1.0	8.1
CAADP Level 1 (CL1)	20.5	−1.0	19.0	17.4	−3.7	14.0	−3.9	12.3	−2.5	11.5
CAADP Level 2 (CL2)	27.5	−6.0	20.8	19.1	−2.4	18.8	−1.6	18.5	0.7	18.5
CAADP Level 3 (CL3)	30.9	−1.4	28.2	27.3	−1.1	27.4	−1.9	24.6	0.2	25.2
CAADP Level 4 (CL4)	28.1	0.9	30.2	26.6	−3.6	23.8	−3.3	22.8	1.2	23.6
NAIP00 (N00)	4.6	4.1	4.8	4.1	−5.2	4.4	3.5	6.2	3.3	7.1
NAIP01 (N01)	14.3	−2.9	12.2	11.1	−3.8	10.6	−0.7	10.3	−0.5	9.9
NAIP10 (N10)	34.7	−8.0	22.7	20.4	−2.7	19.9	−2.9	17.9	−0.3	16.9
NAIP11 (N11)	28.0	0.5	29.1	26.2	−3.1	23.4	−3.0	22.2	0.7	22.6

Source: ReSAKSS based on World Bank (2024).

ANNEX 7a: Supplementary Data Tables

TABLE O.4.1—GROSS DOMESTIC PRODUCT (trillion, constant 2015 US$)										
Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2022)	Annual avg. change (%) (2014-2022)	2022
Africa	1.2	3.9	1.4	1.6	5.9	2.1	3.7	2.6	2.4	2.9
Central	0.1	2.2	0.1	0.1	5.9	0.1	4.8	0.1	2.2	0.1
Eastern	0.1	4.5	0.2	0.2	7.9	0.3	3.2	0.4	3.8	0.4
Northern	0.4	4.0	0.5	0.6	5.3	0.7	2.0	0.8	3.1	0.9
Southern	0.3	3.0	0.3	0.4	5.7	0.5	3.3	0.5	0.6	0.6
Western	0.3	4.6	0.3	0.4	6.0	0.6	6.1	0.7	2.4	0.8
Less favorable agriculture conditions	0.0	5.0	0.0	0.0	5.9	0.0	4.1	0.1	3.7	0.1
More favorable agriculture conditions	0.1	4.7	0.1	0.1	7.4	0.2	6.7	0.3	5.4	0.3
Mineral-rich countries	0.1	3.7	0.1	0.1	8.3	0.1	0.3	0.1	1.1	0.2
Lower middle-income countries	0.7	4.2	0.9	1.0	5.7	1.3	4.6	1.7	2.5	1.8
Upper middle-income countries	0.3	2.7	0.3	0.4	5.4	0.4	0.9	0.5	0.8	0.5
CEN-SAD	0.7	4.3	0.8	0.9	5.9	1.2	3.6	1.5	2.9	1.7
COMESA	0.4	3.6	0.5	0.6	5.9	0.7	2.6	0.9	4.0	1.1
EAC	0.1	2.4	0.1	0.1	8.5	0.2	4.3	0.2	2.0	0.2
ECCAS	0.1	3.5	0.1	0.1	8.5	0.2	4.9	0.2	1.2	0.2
ECOWAS	0.3	4.6	0.3	0.4	6.0	0.6	6.1	0.7	2.4	0.8
IGAD	0.1	4.5	0.1	0.1	8.5	0.2	2.6	0.3	3.6	0.3
SADC	0.4	2.8	0.4	0.5	5.8	0.6	3.7	0.7	1.3	0.7
UMA	0.2	3.4	0.3	0.3	4.8	0.4	1.2	0.4	1.7	0.5
CAADP Compact 2007-09 (CC1)	0.2	4.9	0.3	0.4	6.8	0.5	6.6	0.7	2.6	0.8
CAADP Compact 2010-12 (CC2)	0.2	2.6	0.2	0.2	5.5	0.3	5.6	0.4	4.6	0.5
CAADP Compact 2013-15 (CC3)	0.1	4.5	0.2	0.2	6.6	0.2	3.0	0.3	–0.1	0.3
CAADP Compact not yet (CC0)	0.6	3.6	0.7	0.9	5.5	1.0	1.8	1.2	2.1	1.3
CAADP Level 0 (CL0)	0.6	3.6	0.7	0.9	5.5	1.0	1.8	1.2	2.1	1.3
CAADP Level 1 (CL1)	0.1	4.4	0.1	0.2	6.9	0.2	2.8	0.2	–0.5	0.2
CAADP Level 2 (CL2)	0.0	1.2	0.1	0.1	4.9	0.1	5.4	0.1	4.3	0.1
CAADP Level 3 (CL3)	0.0	5.0	0.0	0.1	6.1	0.1	5.8	0.1	3.9	0.1
CAADP Level 4 (CL4)	0.3	4.4	0.4	0.5	6.5	0.7	6.3	0.9	3.1	1.1
NAIP00 (N00)	0.4	3.5	0.4	0.5	5.6	0.6	2.8	0.7	0.5	0.7
NAIP01 (N01)	0.3	4.0	0.4	0.5	5.7	0.6	1.8	0.7	3.4	0.8
NAIP10 (N10)	0.0	–1.4	0.0	0.0	5.7	0.0	5.9	0.1	4.6	0.1
NAIP11 (N11)	0.5	4.3	0.6	0.6	6.4	0.9	5.4	1.2	2.8	1.3

Source: ReSAKSS based on World Bank (2024).

Note: Aggregate value for a group is the sum of gross domestic product for countries in the group.

ANNEX 7a: Supplementary Data Tables

TABLE O.5.1—GLOBAL HUNGER INDEX (GHI)

Region	Annual avg. level (1995–2003)	Annual avg. change (%) (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (%) (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (%) (2008–2014)	Annual avg. level (2014-2023)	Annual avg. change (%) (2014-2023)	2023
Africa	34.9	−1.3	32.8	31.4	−2.0	28.6	−1.5	24.8	−1.4	23.5
Central	41.8	−1.0	40.1	39.2	−0.8	36.8	−1.4	33.4	−1.0	32.2
Eastern	41.8	−1.7	38.7	36.6	−2.5	32.6	−1.9	27.2	−1.8	25.4
Northern	15.8	−1.1	15.1	14.6	−1.2	13.6	−1.3	12.2	−1.2	11.6
Southern	35.6	−1.4	33.4	31.8	−2.3	28.6	−1.7	23.8	−2.1	22.0
Western	38.3	−1.5	35.7	33.9	−2.5	30.7	−1.3	26.5	−1.4	25.2
Less favorable agriculture conditions	47.7	−1.6	44.3	42.0	−2.5	37.7	−1.5	32.1	−1.8	30.0
More favorable agriculture conditions	44.0	−1.8	40.5	38.1	−2.8	33.7	−1.8	27.8	−2.0	25.7
Mineral-rich countries	41.3	−1.0	39.7	38.6	−1.1	36.4	−1.1	33.3	−1.0	32.1
Lower middle-income countries	29.9	−1.3	28.0	26.8	−2.0	24.4	−1.5	20.9	−1.4	19.8
Upper middle-income countries	18.7	−1.1	17.9	17.4	−0.9	16.3	−1.5	14.6	−1.2	13.9
CEN-SAD	31.9	−1.2	30.1	28.9	−1.9	26.7	−1.2	23.5	−1.2	22.5
COMESA	35.6	−1.2	33.6	32.4	−1.6	29.8	−1.5	26.1	−1.3	24.9
EAC	39.3	−1.3	37.0	35.5	−1.9	32.6	−1.3	27.9	−3.0	22.9
ECCAS	45.4	−1.4	42.6	40.9	−1.7	37.2	−1.8	32.0	−1.5	30.2
ECOWAS	38.3	−1.5	35.7	33.9	−2.5	30.7	−1.3	26.5	−1.4	25.2
IGAD	42.4	−1.8	39.1	37.0	−2.4	32.6	−2.2	26.5	−2.0	24.6
SADC	37.9	−1.2	35.9	34.6	−1.8	32.0	−1.2	28.2	−1.3	26.9
UMA	14.4	−1.3	13.5	12.8	−2.7	11.7	−0.9	10.2	−0.9	10.0
CAADP Compact 2007-09 (CC1)	39.9	−1.5	37.3	35.7	−2.1	33.6	−1.6	28.7	−1.6	26.4
CAADP Compact 2010-12 (CC2)	40.1	−1.2	37.9	36.4	−1.8	34.5	−1.5	29.7	−1.4	27.6
CAADP Compact 2013-15 (CC3)	15.1	−1.3	14.3	13.8	−1.2	13.1	−1.6	11.5	−1.4	10.6
CAADP Compact not yet (CC0)	43.8	−2.0	39.9	37.3	−3.0	34.0	−2.6	26.2	−2.4	23.1
CAADP Level 0 (CL0)	15.1	−1.3	14.3	13.8	−1.2	12.7	−1.7	12.0	0.2	11.9
CAADP Level 1 (CL1)	40.6	−1.1	38.6	37.3	−1.7	34.5	−1.2	30.7	−1.1	29.5
CAADP Level 2 (CL2)	40.1	−1.0	38.4	37.4	−1.2	35.2	−1.0	32.3	−0.9	31.2
CAADP Level 3 (CL3)	39.4	−1.5	36.8	34.9	−2.5	31.3	−1.5	28.5	−0.7	27.4
CAADP Level 4 (CL4)	40.9	−1.7	37.7	35.5	−2.7	31.4	−1.9	26.0	−1.9	24.2
NAIP00 (N00)	22.7	−1.7	21.0	19.9	−2.4	18.4	−2.3	14.3	−0.9	14.9
NAIP01 (N01)	20.4	−0.5	20.0	19.8	−0.5	19.4	−0.5	18.3	−0.4	18.0
NAIP10 (N10)	42.1	−0.7	41.0	40.3	−0.5	39.3	−0.8	36.5	−0.6	35.6
NAIP11 (N11)	39.2	−1.6	36.3	34.4	−2.6	32.0	−2.0	28.0	1.8	36.0

Source: ReSAKSS based on von Grebmer et al. (2023), World Bank (2024), and ILO (2024).

References

ARRANGED BY CHAPTER

Chapter 1

Aidoo, R., E.M. Kwofie, K. Glatzel, and J. Ecuru. 2023. "Bioeconomy: A Path to African Food System Transformation." In *African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, Chapter 10, 173–188. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI).

AUC (African Union Commission). 2022. *Climate Change and Resilient Development Strategy and Action Plan and the 2021 Green Recovery Action Plan*. Addis Ababa: AUC.

AUC. 2024. *CAADP Strategy and Action Plan: 2026–2035. Building Resilient Agri-Food Systems in Africa*. Draft document under validation. Addis Ababa: AUC.

Bugge, M., T. Hansen, and A. Klitkou. 2016. "What Is the Bioeconomy? A Review of the Literature." *Sustainability* 8 (7): 691. https://doi.org/10.3390/su8070691

Climate Analytics. 2023. *When Will Global Emissions Peak?* Berlin: Climate Analytics.

Council of the European Union. 2023. "European Green Deal." Accessed September 17, 2024. https://www.consilium.europa.eu/en/policies/green-deal/

Gatune, J., N. Ozor, and R. Oriama. 2021. "Modelling Bioeconomy Futures for Eastern Africa." *Foresight* 23: 226–241. http://doi.org/10.1108/fs-03-2020-0032

Global Bioeconomy Summit. 2020. *Global Bioeconomy Summit 2020 Conference Report: Expanding the Bioeconomy*. Germany: Global Bioeconomy Summit. https://gbs2020.net/wp-content/uploads/2021/02/GBS_2020_Report_final.pdf

Kruger, A., C. Schafers, P. Busch, and G. Antranikian. 2020. "Digitalization in Microbiology—Paving the Path to Sustainable Circular Bioeconomy." *New Biotechnology* 59: 88–96. doi:10.1016/j.nbt.2020.06.004

Malabo Montpellier Panel. 2022a. *Adapt: Policy Innovations to Unlock Climate Finance for Resilient Food Systems in Africa*. Kigali, Rwanda: Malabo Montpellier Panel.

Malabo Montpellier Panel. 2022b. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy Report*. Kigali, Rwanda: Malabo Montpellier Panel.

Nyarko, I., C. Nwaogu, H. Miroslav, and P.O. Peseu. 2021. "Socio-economic Analysis of Wood Charcoal Production as a Significant Output of Forest Bioeconomy in Africa." Forests 12 (5): 568. https://doi.org/10.3390/f12050568

Ulimwengu, J. M., Kwofie, E.M., and Collins, J. (Eds.) 2023. *ReSAKSS 2023 Annual Trends and Outlook Report: African Food Systems Transformation and the Post-Malabo Agenda*. Kigali and Washington, DC: AKADEMIYA2063 and International Food Policy Research Institute (IFPRI).

WMO (World Meteorological Organization). 2023. *Early Warnings for All in Focus: Hazard Monitoring and Forecasting*. Geneva: WMO. https://wmo.int/files/early-warnings-all-focus-hazard-monitoring-and-forecasting

WFP (World Food Program). 2024. "Urgent Call to Action to Address Historic El Niño Drought in Southern Africa." WFP, June 5. https://www.wfp.org/news/urgent-call-action-address-historic-el-nino-drought-southern-africa

Chapter 2

Aidoo, R., K.M. Ebenezer, K. Glatzel, and J. Ecuru. 2023. "Bioeconomy: A Path to African Food Systems Transformation." In *ReSAKSS 2023 Annual Trends and Outlook Report: African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, Chapter 10. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.54067/9781737916482

AUC (African Union Commission). 2021. *Africa Common Position on Food Systems*. Addis Ababa, Ethiopia: AUC.

AUC. 2023. *Fourth CAADP Biennial Review Repor*t. Addis Ababa, Ethiopia: AUC.

AUC. 2014. *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC and AUDA-NEPAD (African Union Development Agency). 2023. Plan for the Development of the *Post-Malabo Agenda for Action on CAADP: Propelling Africa's Agricultural Growth and Agri-Food Systems Transformation to Boost Economic Transformation, Food Sovereignty and Resilience*. Addis Ababa, Ethiopia: AUC.

AUC, AUDA-NEPAD, and AKADEMIYA2063. 2024. *Post-Malabo Agenda Analytical Support Workstream. Overall Design and Terms of Reference*. Ethiopia: AUC

AUC and NPCA (NEPAD Planning and Coordinating Agency). 2015. *The CAADP Results Framework 2015–2025: Going for Results and Impacts*. Addis-Ababa: AUC.

AUC and UNECA (United Nations Economic Commission for Africa). 2013. *Africa Bioenergy Policy Framework and Guidelines: Towards Harmonizing Sustainable Bioenergy Development in Africa.* Addis Ababa, Ethiopia: AUC and UNECA. https://au.int/sites/default/files/documents/32183-doc-africa_bioenergy_policy-e.pdf

BioInnovate Africa. 2019. "Bio-alkanol Gel Fuel for Rural Households in the Lake Victoria Basin." Accessed August 30, 2024. https://bioinnovate-africa.org/bio-alkanol-gel-fuel-for-rural-households-in-the-lake-victoria-basin/

Badiane, O. 2023. *From Community Vulnerability and Nutritional Status to Crisis Preparedness and Response Capacity.* Kigali, Rwanda: AKADEMIYA2063

Chala, B., H. Oechsner, S. Latif, and J. Müller. 2018. "Biogas Potential of Coffee Processing Waste in Ethiopia." *Sustainability* 10 (8): 2678. https://doi.org/10.3390/su10082678

FAO (Food and Agricultural Organization of the United Nations). 2018. *Moving Forward: Selected Achievements of the FAO Forestry Programme 2016-2020.* Rome: FAO. https://openknowledge.fao.org/server/api/core/bitstreams/88ce4dd7-a1f7-4cfe-a98e-8fb2e492551c/content

Fleming, S. 2019. "The Clothes of the Future Could Be Made from Pineapples and Bananas." *WEForum Agenda Articles*, April 2. https://www.weforum.org/agenda/2019/04/the-clothes-of-the-future-could-be-made-from-pineapples-and-bananas/

Fraunhofer Institute. 2020. "Agricultural Side Streams Aimed at Breeding Insects for Food Production." Accessed August 30, 2024. https://www.ivv.fraunhofer.de/en/food/development/entomo.html

Global Bioeconomy Summit. 2020. "About the Global Bioeconomy Summit." https://gbs2020.net/about/conference/

Gomez San Juan, M., A. Bogdanski, and O. Dubois. 2019. *Towards Sustainable Bioeconomy - Lessons Learned from Case Studies*. Rome: FAO.

Helgason, K., K. Iversen, and A. Julca. 2021. *Circular Agriculture for Sustainable Rural Development*. UN/DESA Policy Brief #105. New York: United Nations Department of Economic and Social Affairs (UN DESA). https://desapublications.un.org/policy-briefs/undesa-policy-brief-105-circular-agriculture-sustainable-rural-development

Jayaprakash, K., A. Osama, R. Rajagopal, B. Goyette, and O.P. Karthikeyan. 2022. "Agriculture Waste Biomass Repurposed into Natural Fibers: A Circular Bioeconomy Perspective." *Bioengineering* 9 (7): 296.

Jonsson, R., F. Rinaldi, R. Pilli, G. Fiorese, E. Hurmekoski, N. Cazzaniga, N. Robert, and A. Camia. 2021. "Boosting the EU Forest-Based Bioeconomy: Market, Climate, and Employment Impacts." *Technological Forecasting and Social Change* 163: 120478. https://doi.org/10.1016/j.techfore.2020.120478

Malabo Montpellier Panel. 2024. *Youth Ahead: Policy Innovations to Create Opportunities for Young People in Africa's Agrifood Systems.* Kigali, Rwanda: AKADEMIYA2063. https://www.mamopanel.org/resources/reports-and-briefings/youth-ahead-policyinnovations-create-opportunitie/

Malabo Montpellier Panel. 2022. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy*. Kigali, Rwanda: AKADEMIYA2063. https://www.mamopanel.org/media/uploads/files/Bioeconomy_Report-Malabo_Montpellier_Panel-May_24_2022_WdoAcqS.pdf

Mbow, C., M. Manyewu, and A. Diatta et al. 2024. "Enhancing Resilience of Livelihoods and Agri-food Systems to Shocks." Unpublished Technical Working Group 10 Report submitted to AKADEMIYA2063 as contribution to the post-Malabo CAADP agenda setting.

Olayide, O.E., P. Elago, C. Duarte, and B. B. Keizire et al. 2024. "Principles and Values of the CAADP Process (from Narrow Agriculture-led Growth to Agri-food System)." Unpublished Technical Working Group 1 Report submitted to AKADEMIYA2063 as contribution to the post-Malabo CAADP agenda setting.

PRB (Population Reference Bureau). 2019. *Africa's Future: Youth and the Data Defining Their Lives*. Policy brief. Washington, DC: PRB. https://www.prb.org/wp-content/uploads/2019/10/Status-of-African-YouthSPEC.pdf

Provin, A.P. and de Aguiar Dutra, A.R., 2021. Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles. *Technological Forecasting and Social Change, 169*, p.120858.

Rocca, C., and I. Schultes. 2020. *Africa's Youth: Action Needed Now to Support the Continent's Greatest Asset*. Research brief. London: Mo Ibrahim Foundation. https://www.prb.org/resources/africas-future-youth-and-the-data-defining-their-lives/

SIANI (Swedish International Agricultural Network Initiative). 2016. *Developing Knowledge-Based Bioeconomies in Sub-Saharan Africa: How Can Sweden Help?* Policy Brief November 2016. Stockholm: SIANI. https://www.siani.se/wp-content/uploads/2017/10/161111a_bessanova_siani_brief_1610-27.compressed1.pdf

Statista. 2024. "Median Age of the Population of Africa from 2000 to 2030." Accessed August, 20, 2024. https://www.statista.com/statistics/1226158/median-age-of-the-population-of-africa/#:~:text=In%202022%2C%20the%20median%20age,it%20was%20around%2017%20years

Ulimwengu, J., A. Wambo Yamdjeu, C. Namukolo, and B.B. Keizire et al. 2024. "Theory of Change and Results Framework for Post-Malabo CAADP Agenda: Building Sustainable, Resilient, and Inclusive Agri-food Systems that Deliver Economic Prosperity, Livelihoods, Better Diets and Nutrition for All Africans." Unpublished Technical Working Group 10 Report submitted to AKADEMIYA2063 as contribution to the post-Malabo CAADP agenda setting.

UNECA (United Nations Economic Commission for Africa). 2023. "ECA Calls for Africa's Economic Growth to be Inclusive to Reduce Widespread Poverty." *UNECA Stories*, March 23. https://www.uneca.org/stories/eca-calls-for-africa%27s-economic-growth-to-be-inclusive-to-reduce-widespread-poverty

UNOSSC (United Nations Office for South-South Cooperation). 2020. *South-South and Triangular Cooperation on the Bioeconomy in Light of the Paris Agreement and the 2030 Agenda for Sustainable Development*. New York: UNOSSC. https://unsouthsouth.org/wp-content/uploads/2020/08/triangular-cooperation-on-the-bioeconomy-publication.pdf

Wambo Yamdjeu, A., and H. Diop. 2024. *Thematic Guidance to Inform Stakeholder Dialogues in the Post- Malabo Agenda Development Process*. Post-Malabo Issue Paper Series, No. 1. Kigali, Rwanda: AKADEMIYA2063.

Chapter 3

AfDB (African Development Bank). 2019. "Climate Change Impacts on Africa's Economic Growth." Abidjan, Côte d'Ivoire.

Andersson, C., A. Mekonnen, and J. Stage. 2011. "Impacts of the Productive Safety Net Program in Ethiopia on Livestock and Tree Holdings of Rural Households." *Journal of Development Economics* 94: 119–26.

Badiane, O., and J. Collins. 2020. "Strengthening National Institutions for Tangible and Sustainable Impacts at Scale." In *Inclusive Growth: Making Value Chains Work for Smallholder Farmers*, 98–113. Jeddah, Saudi Arabia: Islamic Development Bank Group.

Badiane, O., S.P. Odjo, and S. Jemaneh. 2014. "More Resilient Domestic Food Markets through Regional Trade." In *ReSAKSS Annual Trends and Outlook Report 2013: Promoting Agricultural Trade to Enhance Resilience in Africa,* eds. O. Badiane, T. Makombe, and G. Bahiigwa, 38–53. Washington, DC: International Food Policy Research Institute (IFPRI).

Barrios, S., B. Ouattara, and E. Strobl. 2008. "The Impact of Climatic Change on Agricultural Production: Is It Different for Africa?" *Food Policy* 33 (4): 287–298.

Benin, S., E. Nkonya, G. Okecho, J. Pender, S. Nahdy, S. Mugarura, E. Kato, and G. Kayobyo. 2007. "Assessing the Impact of the National Agricultural Advisory Services (NAADS) in the Uganda Rural Livelihoods." IFPRI Discussion Paper 00724. IFPRI, Washington, DC. http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/125292/filename/125293.pdf

Bonuedi, I., K. Kamasa, and E.E.O. Opoku. 2020. "Enabling Trade across Borders and Food Security in Africa." *Food Security* 12: 1121–1140.

Challinor, A.J., J. Watson, D.B. Lobell, S.M. Howden, D.R. Smith, and N. Chhetri. 2014. "A Meta-analysis of Crop Yield under Climate Change and Adaptation." *Nature Climate Change* 4: 287–291.

Deason, L., D.D. Laborde, N. Minot, R. Shahidur, and M. Torero. 2014. "Food Price Volatility: Effects and Response Mechanisms in Africa." In *ReSAKSS Annual Trends and Outlook Report 2013: Promoting Agricultural Trade to Enhance Resilience in Africa*, eds. O. Badiane, T. Makombe, and G. Bahiigwa, 18–37. Washington, DC: IFPRI.

Diao, X., P. Hazell, and J. Thurlow. 2010. "The Role of Agriculture in African Development." *World Development* 38 (10): 1375–1383.

Diao, X., M. Ellis, K. Pauw, and J. Thurlow. 2023a. *Ethiopia's Agrifood System: Structure and Drivers of Transformation*. Country Brief 4. Washington, DC: IFPRI. https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/136808/filename/137019.pdf

Diao, X., M. Ellis, K. Pauw, and J. Thurlow. 2023b. *Zambia's Agrifood System: Structure and Drivers of Transformation*. Country Brief 21. Washington, DC: IFPRI. https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/136797/filename/137006.pdf

FAO (Food and Agriculture Organization of the United Nations). 2014. *Lesotho's Child Grant Programme: 24-month Impact Report on Productive Activities and Labour Allocation*. Rome. Http://Www.Fao.Org/3/a-I4186e.Pdf

FAO. 2018. Tackling Poverty and Hunger through Digital Innovation. Rome: FAO.

FAO. 2022. "The State of Social Protection for Agrifood Systems Workers in West Africa." Working Paper No. 196. Rome. https://www.fao.org/3/cc3310en/cc3310en.pdf

FAO. 2021. "The State of Food and Agriculture 2021: Making Agrifood Systems More Resilient to Shocks and Stresses." Rome.

FAO. 2022. *The Transformation of Agri-food Systems in Times of Multiple Crises*. Rome. https://assets.ctfassets.net/rrirl83ijfda/4liyQq8ymcuQx5b0S0UnJH/aa07d204d3cd0b2a63d38dcb4cd8ef75/TMG_FORESEEseries_SummaryReport-2023.03.16.pdf

FAO, IFAD (International Fund for Agricultural Development), and AGRA (Alliance for a Green Revolution in Africa). 2021. *A Technical Review of Select De-risking Schemes to Promote Rural and Agricultural Finance in Sub-Saharan Africa*. Rome. https://www.fao.org/3/cb6625en/cb6625en.pdf

Fofana, I. 2023a. "Economic Impacts of Climate Change and Adaptation Strategies in Mali" CACCI Field Notes No. 4. Kigali, Rwanda: AKADEMIYA2063. https://doi.org/10.54067/caccifn.04

Fofana, I. 2023b. "Economic Impacts of Climate Change and Adaptation Strategies in Kenya." CACCI Field Notes No. 3. Kigali, Rwanda: AKADEMIYA2063. https://doi.org/10.54067/caccifn.03

Fofana, I., R. Ly, G. Tadesse, F. Wouterse, and A. Zongo. 2023. *The Macroeconomics of Climate Change and Adaptation Options in Agriculture: Evidence from Kenya and Mali*. Kigali, Rwanda: AKADEMIYA2063.

Fofana, I., and S. Sadio Diallo. 2024. "Impacts Économiques du Changement Climatique et Options d'Adaptation au Sénégal." Note de terrain CACCI, No. 13. Kigali : AKADEMIYA2063. https://doi.org/10.54067/caccifn.013

Geda, A., A. Yimer, T. Demissie, M. Radeny, G. Kassie, A. Tesfaye, B. Belay, and D. Solomon. 2023. "Unraveling the Climate-Macro Conundrum: The Macroeconomic Impact of Climate Change in Eastern Africa." AICCRA Working Paper No. 13. Accelerating Impacts of CGIAR Climate Research in Africa (AICCRA).

Ghins, L. and K. Zougbédé. 2019. "The Food Economy Can Create More Jobs for West African Youth." *OECD Development Matters*, August 23. https://oecd-development-matters.org/2019/08/23/the-food-economy-can-create-more-jobs-for-west-african-youth/

Haggblade, S., P.B.R. Hazell, and P.A. Dorosh. 2007. "Sectoral Growth Linkages Between Agriculture and the Rural Nonfarm Economy." In *Transforming the Rural Nonfarm Economy Opportunities and Threats in the Developing World*, eds. S. Haggblade, P.B.R. Hazell, and T. Reardon, Chapter 7. Baltimore, MD: Johns Hopkins University Press.

Hall, A., J. Dijkman, and R. Sulaiman. 2010. "Research into Use: Investigating the Relationship between Agricultural Research and Innovation." UNU-MERIT Working Paper. United Nations University, Maastricht, Netherlands.

Hoddinott, J., S. Devereux, P. White, S. Klasen, I. Woolard, H. Alderman, O. Badiane, J. Ulimwengu, and F. Wouterse. 2012. *Social Protection in West Africa: The Status Quo, Lessons from Other Regions, Implications for Research*. Thematic Research Note No. 3. Washington, DC: IFPRI. https://au.int/sites/default/files/documents/30933-doc-ifpri_wcao_trn3_social_protection_0.pdf

Horton, P., S.A. Banwart, D. Brockington, G.W. Brown, R. Bruce, D. Cameron, M. Holdsworth, S.C. Lenny Koh, J. Ton, and P. Jackson. 2017. "An Agenda for Integrated System-Wide Interdisciplinary Agri-food Research." *Food Security* 9: 195–210.

IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022: Mitigation of Climate Change*. Cambridge, UK: Cambridge University Press.

Kumar, L., N. Chhogyel, T. Gopalakrishnan, et al. 2022. "Climate Change and Future of Agri-food Production." In *Future Foods Global Trends, Opportunities, and Sustainability Challenges*, 49–79. Academic Press.

Kumar, L., N. Chhogyel, T. Gopalakrishnan, M.K. Hasan, S.L. Jayasinghe, C.S. Kariyawasam, B.K. Kogo, and S. Ratnayake. 2022. "Climate Change and Future of Agri-food Production." In *Future Foods Global Trends, Opportunities, and Sustainability Challenges*, Chapter 4, 49-79. London: Academic Press.

Levy, S. 2005. *Starter Packs: A Strategy to Fight Hunger in Developing Countries? Lessons from the Malawi Experience*. Wallingford, UK: CAB International.

Lynam, J., N.M. Beintema, J. Roseboom, and O. Badiane. 2016. "Investment in Agricultural Research and Development: An Account of Two-Speed Growth, Underinvestment, and Volatility." In *Agricultural Research in Africa: Investing in Future Harvests*, 85–108. Washington, DC: International Food Policy Research Institute (IFPRI).

Mahofa, G. 2021. *Climate Change and Agricultural Trade in Sub-Saharan Africa*. Nairobi: African Economic Research Consortium. https://aercafrica.org/old-website/wp-content/uploads/2021/11/PB777Eng-3.pdf

Malabo Montpellier Panel. 2019. *Policy Innovation for Transforming Africa's Food System with Digital Technologies*. Kigali, Rwanda: AKADEMIYA2063. https://www.mamopanel.org/media/uploads/files/2019_MaMo_Digital_Report_ONLINE_UiUPwum.pdf

Malabo Montpellier Panel. 2020. "Trading Up: Policy Innovations to Expand Food and Agricultural Trade in Africa." Paper presented at the 7th Malabo Montpellier (MaMo) Forum, December 21.

Mbabu, A.N., and C.M.O. Ochieng. 2006. "Building an Agricultural Research for Development System in Africa." ISNAR Discussion Paper 8. IFPRI, Washington, DC. https://core.ac.uk/download/pdf/67846.pdf

Okodua, H., V. Sedegan, and M. Tankari. 2024. *Climate Change and Adaptation Pathways for Rwanda*. CACCI Field Notes, No. 15. Kigali: AKADEMIYA2063. https://doi.org/10.54067/caccifn.015

Okodua, H., I. Fofana, and G. Tadesse. Forthcoming. Climate Adaptation Status and Pathways in Nigeria.

Pellerano, L., M. Moratti, M. Jakobsen, M. Bajgar, and V. Barca. 2014. *Child Grants Programme Impact Evaluation: Follow-up Report*. Rome: FAO.

Rateng, B. 2016. "Mobile App for Rain Forecasts Raising Farmers' Yields." *SciDev News*, July 12. https://www.scidev.net/sub-saharan-africa/icts/news/mobile-app-rain-forecasts-farmers-yields.html

Ringler, C., M.W. Rosegrant, N. Perez, and H. Xie. 2021. "The Future of Irrigation: Farmer-Led." Paper prepared for the Water for Food international Forum (WFIF) 2021, October 1–October 31.

Sato, L., and N. Mohamed. 2022. *The Role of Social Insurance Schemes in Addressing the Risks Faced by Agricultural Workers in the Middle East and North Africa*. Research Report No. 80. Cairo: FAO Regional Office for the Near East and North Africa; Beirut: International Labour Organization (ILO) Regional Office for Arab States; Brasília, Brazil: International Policy Centre for Inclusive Growth (IPC-IG).

Sibindi, N. 2020. *Nexus between Food Security and Trade in the Run-up to the World Food Systems Summit*. Johannesburg, South Africa: South Africa institute of International Affairs (SAIIA). https://saiia.org.za/research/nexus-between-food-security-and-trade-in-the-run-up-to-the-world-food-systems-summit/

SWAC/OECD (Sahel and West Africa Club). 2022. *Food System Transformations in the Sahel and West Africa: Implications for People and Policies*. Paris: OECD Publishing.

Takamgno, C.S., P.J.N. Tegoum, N.F. Mayap, F.M. Petga, Y.F.M. Kuete, A.P.Y. Noutanewo. 2023. "The Gender Impact of Public Climate Change Adaptation Policies on Food Security in Cameroon." Working Paper 2023-11. PEP Working Paper Series. Partnership of Economic Policy.

Thornton, P., A. Gosling, S. Chesterman, and C.N. Neely. 2022. *The Impacts of Climate Change on Southern African Food Systems*. AICCRA.

UNECA (United Nations Economic Commission for Africa), AU (African Union), AfDB, UNCTAD (United Nations Conference on Trade and Development). 2019. *Assessing Regional Integration in Africa IX: Next Steps for the African Continental Free Trade Area*. Addis Ababa, Ethiopia.

University of Notre Dame. 2021, "Rankings // Notre Dame Global Adaptation Initiative // University of Notre Dame." *Notre Dame Global Adaptation Initiative*. https://gain.nd.edu/our-work/country-index/rankings/

van Ginneken, W. 2005. *Managing Risk and Minimizing Vulnerability: The Role of Social Protection in Pro-Poor Growth*. Geneva: ILO.

World Bank. 2015. *Future of Food: Shaping a Climate-Smart Global Food System*. Washington, DC. https://hdl.handle.net/10986/22927

WMO (World Meteorological Organization). 2023. *State of the Climate in Africa 2022*. https://library.wmo.int/idurl/4/67761

Chapter 4

Abdelkrim, B.S., R. Laila, and K. Ahmed. 2022. Climatic and Environmental Significance of Wetlands: Case Studies from Eurasia and North Africa.. IGI Global.

Allen, J.T. 2018. "Climate Change and Severe Thunderstorms." Oxford Research Encyclopedia of Climate Science, July 30. https://doi.org/10.1093/acrefore/9780190228620.013.62

Bandh, S.A., S. Shafi, M. Peerzada, T. Rehman, S. Bashir, S.A. Wani, and R. Dar. 2021. "Multi-dimensional Analysis of global Climate Change: A Review." Environmental Science and Pollution Research 28: 24872–24888. https://doi.org/10.1007/s11356-021-13139-7

Chatterjee, D., S.R. Das, S. Saha, A. Sarkar, and H. Pathak. 2024. "Impacts of Climate Change on Soil Processes." In Climate Change Impacts on Soil-Plant-Atmosphere Continuum, eds. H. Pathak, D. Chatterjee, S. Saha, and B. Das, 3–36. Singapore: Springer Nature. https://doi.org/10.1007/978-981-99-7935-6_1

Chen, H., T. Zhu, B. Li, C. Fang, and M. Nie. 2020. "The Thermal Response of Soil Microbial Methanogenesis Decreases in Magnitude with Changing Temperature." Nature Communications 11: 5733. https://doi.org/10.1038/s41467-020-19549-4

Cook, B.I., J.S. Mankin, and K.J. Anchukaitis. 2018. "Climate Change and Drought: From Past to Future." Current Climate Change Reports 4: 164–179. https://doi.org/10.1007/s40641-018-0093-2

Cui, M., A. Ma, H. Qi, X. Zhuang, G. Zhuang, and G. Zhao. 2015. "Warmer Temperature Accelerates Methane Emissions from the Zoige Wetland on the Tibetan Plateau without Changing Methanogenic Community Composition." Scientific Reports 5: 11616. https://doi.org/10.1038/srep11616

Cusworth, D.H., R.M. Duren, A.K. Ayasse, R. Jiorle, K. Howell, A. Aubrey, R.O. Green, M.E. Eastwood, et al. 2024. "Quantifying Methane Emissions from United States Landfills." Science 383 (6690): 1499–1504. https://doi.org/10.1126/science.adi7735

de Vries, J., R. Voors, B. Ording, J. Dingjan, P. Veefkind, A. Ludewig, Q. Kleipool, R. Hoogeveen, and I. Aben. 2016. "TROPOMI on ESA's Sentinel 5p Ready for Launch and Use." Paper presented at the Fourth International Conference on Remote Sensing and Geoinformation of the Environment, Paphos, Cyprus, August 12. https://doi.org/10.1117/12.2240839

Desjardins, R.L., D.E. Worth, E. Pattey, A. VanderZaag, R. Srinivasan, M. Mauder, D. Worthy, C. Sweeney, and S. Metzger. 2018. "The Challenge of Reconciling Bottom-Up Agricultural Methane Emissions Inventories with Top-Down Measurements." Agricultural and Forest Meteorology 248: 48–59. https://doi.org/10.1016/j.agrformet.2017.09.003

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, et al. 2007. "Couplings Between Changes in the Climate System and Biogeochemistry." In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Chapter 7. Cambridge, UK: Cambridge University Press.

Dlugokencky, E.J., L. Bruhwiler, J.W.C. White, and L.K. Emmons. 2009. "Observational Constraints on Recent Increases in the Atmospheric CH4 Burden." Atmospheric Science 36 (18): L18803. https://doi.org/10.1029/2009GL039780

Guanter, L., I. Aben, P. Tol, J.M. Krijger, A. Hollstein, P. Köhler, A. Damm, J. Joiner, C. Frankenberg, and J. Landgraf. 2015. "Potential of the TROPOspheric Monitoring Instrument (TROPOMI) Onboard the Sentinel-5 Precursor for the Monitoring of Terrestrial Chlorophyll Fluorescence." Atmospheric Measurement Techniques 8 (3): 1337–1352. https://doi.org/10.5194/amt-8-1337-2015

IEA (International Energy Agency). 2023. World Energy Outlook 2023. Paris: IEA. https://www.iea.org/reports/world-energy-outlook-2023

IPCC (Intergovernmental Panel on Climate Change). 2023. "Summary for Policymakers." In *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds. H. Lee and J. Romero. Geneva: IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

Jacob, D.J., A.J. Turner, J.D. Maasakkers, J. Sheng, K. Sun, X. Liu, K. Chance, I. Aben, J. McKeever, and C. Frankenberg. 2016. "Satellite Observations of Atmospheric Methane and Their Value for Quantifying Methane Emissions." *Atmospheric Chemistry and Physics* 16 (22): 14371–14396. https://doi.org/10.5194/acp-16-14371-2016

Joseph, C.M. 2024. "Livestock Emission Reduction Policies and their Impact on Greenhouse Gas Emissions in Peru." American Journal of Livestock Policy 4 (1): 18–27. https://doi.org/10.47672/ajlp.1773

Kogo, B.K., L. Kumar, and R. Koech. 2021. "Climate Change and Variability in Kenya: A Review of Impacts on Agriculture and Food Security." Environment, Development and Sustainability 23: 23–43. https://doi.org/10.1007/s10668-020-00589-1

Kooreman, M.L.,P. Stammes, V. Trees, M. Sneep, L. Gijsbert Tilstra, M. de Graaf, D.C. Stein Zweers, P. Wang, O.N.E. Tuinder, and J. Pepijn Veefkind. 2020. "Effects of Clouds on the UV Absorbing Aerosol Index from TROPOMI." Atmospheric Measurement Techniques 13 (12): 6407–6426. https://doi.org/10.5194/amt-13-6407-2020

Liu, Y., J. Wang, K. Che, Z. Cai, D. Yang, and L. Wu. 2021. "Satellite Remote Sensing of Greenhouse Gases: Progress and Trends." National Remote Sensing Bulletin 25 (1): 53–64. https://doi.org/10.11834/jrs.20210081

Määttä, T., and A. Malhotra. 2024. "The Hidden Roots of Wetland Methane Emissions." Global Change Biology 30 (2): e17127. https://doi.org/10.1111/gcb.17127

Malhi, G.S., M. Kaur, and P. Kaushik. 2021. "Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review." Sustainability 13 (3): 1318. https://doi.org/10.3390/su13031318

Mostefaoui, M., P. Ciais, M.J. McGrath, P. Peylin, P.K. Patra, and Y. Ernst. 2024. "Greenhouse Gas Emissions and Their Trends over the Last 3 Decades across Africa." Earth System Science Data 16 (1): 245–275. https://doi.org/10.5194/essd-16-245-2024

Nwaneke, P., and V. Chude. 2015. "Socioeconomic Impact of Climate Change in Northern Nigeria." Paper presented at the Proceedings of the 39th Annual Conference of the Soil Society of Nigeria, Landmark University, Omu-Aran, Kwara State, Nigeria, March 9–15.

Omotoso, A.B., and A.O. Omotayo. 2023. "The Interplay between Agriculture, Greenhouse Gases, and Climate Change in Sub-Saharan Africa." Regional Environmental Change 24: 1. https://doi.org/10.1007/s10113-023-02159-3

Ouyang, Z., R.B. Jackson, G. McNicol, E. Fluet-Chouinard, B.R.K. Runkle, D. Papale, S.H. Knox, et al. 2023. "Paddy Rice Methane Emissions across Monsoon Asia." Remote Sensing of the Environment 284: 113335. https://doi.org/10.1016/j.rse.2022.113335

Parkes, B., J.R. Buzan, and M. Huber. 2022. "Heat Stress in Africa under High Intensity Climate Change." International Journal of Biometeorology 66: 1531–1545. https://doi.org/10.1007/s00484-022-02295-1

Reay, D., P. Smith, and A. van Amstel. 2010. Methane and Climate Change. New York: Earthscan.

Reinelt, T., A. Delre, T. Westerkamp, M.A. Holmgren, J. Liebetrau, and C. Scheutz. 2017. "Comparative Use of Different Emission Measurement Approaches to Determine Methane Emissions from a Biogas Plant." Waste Management 68: 173–185. https://doi.org/10.1016/j.wasman.2017.05.053

Shaw, J.T., G. Allen, P. Barker, J.R. Pitt, D. Pasternak, S.J-B. Bauguitte, J. Lee, et al. 2022. "Large Methane Emission Fluxes Observed From Tropical Wetlands in Zambia." Global Biogeochemical Cycles 36 (6): e2021GB007261. https://doi.org/10.1029/2021GB007261

Skytt, T., S.N. Nielsen, and B-G. Jonsson. 2020. "Global Warming Potential and Absolute Global Temperature Change Potential from Carbon Dioxide and Methane Fluxes as Indicators of Regional Sustainability – A Case Study of Jämtland, Sweden." Ecological Indicators 110: 105831. https://doi.org/10.1016/j.ecolind.2019.105831

UNEP (United Nations Environment Programme). 2021. Annual Report 2021. Nairobi, Kenya: UNEP.

Usiabulu, G.I., D. André, P.S. Aprioku, A. Tunde, D.E. Aguebor, O. Ogechi, D.I. Ucheana, J.F. Peters, and N. Ayafor. 2024. "Climate Change Impacts and Mitigation Strategies in the Energy Sector of African Countries." Journal of Engineering Research and Report 26 (2): 69–88. https://doi.org/10.9734/jerr/2024/v26i21073

van Amstel, A. 2012. "Methane. A Review." Journal of Integrative Environmental Science 9 (sup1): 5–30. https://doi.org/10.1080/1943815X.2012.694892

Winsemius, H.C., B. Jongman, T.I.E. Veldkamp, S. Hallegatte, M. Bangalore, and P.J. Ward. 2018. “Disaster Risk, Climate Change, and Poverty: Assessing the Global Exposure of Poor People to Floods and Droughts.” Environment and Development Economics 23 (Special Issue 3): 328–348. https://doi.org/10.1017/S1355770X17000444

Yaman, C. 2024. “A Review on the Process of Greenhouse Gas Inventory Preparation and Proposed Mitigation Measures for Reducing Carbon Footprint.” Gases 4 (1): 18–40. https://doi.org/10.3390/gases4010002

Zhang, C., X. Comas, and D. Brodyle. 2020. “A Remote Sensing Technique to Upscale Methane Emission Flux in a Subtropical Peatland.” Journal of Geophysical Research: Biogeosciences 125 (10): e2020GJ006002. https://doi.org/10.1029/2020JG006002

Chapter 5

Adger, W.N. 2006. “Vulnerability Global Environmental Change.” *Global Environmental Change* 16 (3): 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006 0

Africa CDC (Africa Centres for Disease Control and Prevention). 2024. “Communiqué from Africa CDC on the Southern Africa Development Community (SADC) Extra Ordinary Virtual Summit of Heads of State and Government on the Cholera Situation in the Region.” *Africa CDC News*, February https://africacdc.org/news-item/communique-from-africa-cdc-on-the-southern-africa-development-community-sadc-extra-ordinary-virtual-summit-of-heads-of-state-and-government-on-the-cholera-situation-in-the-region/

Agostoni, C., M. Baglioni, A. La Vecchia, G. Molari, and C. Berti. 2023. “Interlinkages between Climate Change and Food Systems: The Impact on Child Malnutrition-Narrative Review.” *Nutrients* 15 (2): 416. https://doi.org/10.3390/nu15020416

Alcayna, T., I. Fletcher, R. Gibb, L. Tremblay, S. Funk, B. Rao, and R. Lowe. 2022. “Climate-Sensitive Disease Outbreaks in the Aftermath of Extreme Climatic Events: A Scoping Review.” *One Earth* 5 (4): 336–350.

Atwoli, L., J. Muhia, and Z. Merali. 2022. “Mental Health and Climate Change in Africa.” *BJPsych Internationa*l 19 (4): 86–89. https://doi.org/10.1192/bji.2022.14

Ayalew, A., F.O. Kareem, and D. Grace. 2023. “A Paradigm Shift in Food Safety for Africa.” In *ReSAKSS 2023 Annual Trends and Outlook Report: African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, 106–120. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI).

Badolo A, A. Sombié, F. Yaméogo, D.W. Wangrawa, A. Sanon, O.M. Pignatelli, A. Sanon, M. Viana, H. Kanuka, D. Weeman, and P.J. McCall. 2022 “First Comprehensive Analysis of *Aedes aegypt*i Bionomics During an Arbovirus Outbreak in West Africa: Dengue in Ouagadougou, Burkina Faso, 2016–2017.” PLoS Neglected Tropical Diseases 16 (7): e0010059. https://doi.org/10.1371/journal.pntd.0010059

Bett, B., P. Kiunga, J. Gachohi, C. Sindato, D. Mbotha, T. Robinson, J. Lindahl, and D. Grace. 2017. “Effects of Climate Change on the Occurrence and Distribution of Livestock Diseases.” *Preventive Veterinary Medicine* 137 (Part B): 119-129. https://doi.org/10.1016/j.prevetmed.2016.11.019

Birkmann, J., E. Liwenga, R. Pandey, E. Boyd, R. Djalante, F. Gemenne, W. Leal Filho, P.F. Pinho, L. Stringer, and D. Wrathall. 2022. “Poverty, Livelihoods and Sustainable Development.” In Climate Change 2022: Impacts, Adaptation and Vulnerability, eds. H-O. Pörtner, D.C. Roberts, M.M.B. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegria, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, 1171–1284. Cambridge, UK: Cambridge University Press.

Brooks, N. 2003. “Vulnerability, Risk and Adaptation: A Conceptual Framework.” Working Paper 38. Tyndall Centre for Climate Change Research, Norwich, UK.

Burton, I. 1997. “Vulnerability and Adaptive Responses in the Context of Climate and Climate Change.” *Clim. Chang*e 36: 185–196.

Caminade, C., K.M. McIntyre, and A.E. Jones. 2019. “Impact of Recent and Future Climate Change on Vector-borne Diseases.” *Annals of the New York Academy of Sciences* 1436 (1): 157–173.

Cissé, G., J.A. Menezes, and U. Confalonieri. “Climate-Sensitive Infectious Diseases.” In *The Adaptation Gap Report 2018,* 49–59.Nairobi, Kenya: United Nations Environment Programme (UNEP).

Climate Reanalyzer. 2024. “Climate Reanalyzer: Data and Maps.” University of Maine. https://climatereanalyzer.org

Didan, K. 2015. MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006 dataset. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/MODIS/MOD13Q1.006

Dunne, D. 2023. "Analysis: Africa's Extreme Weather Has Killed at Least 15,000 People in 2023." *Carbon Brief*, October 25. https://www.carbonbrief.org/analysis-africas-extreme-weather-have-killed-at-least-15000-people-in-2023/

Eyring, V., S. Bony, G.A. Meehl, C.A. Senior, B. Stevens, R.J. Stouffer, and K.E. Taylor. 2016. "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization." *Geoscientific Model Development* 9 (5): 1937–1958. https://doi.org/10.5194/gmd-9-1937-2016

Funk, C., P. Peterson, M. Landsfeld, D. Pedreros, J. Verdin, S. Shukla, G. Husak, J. Rowland, L. Harrison, A. Hoell, and J. Michaelsen. 2015. "The Climate Hazards InfraRed Precipitation with Stations—A New Environmental Record for Monitoring Extremes." *Scientific Data* 2: 150066. https://doi.org/10.1038/sdata.2015.66

Gaudiaut, T. 2023. "Quels Sont les Effets d'El Niño sur le Climat Mondial?" October 20. https://fr.statista.com/infographie/31090/carte-des-impacts-effets-du-phenomene-el-nino-sur-climat-mondial/

Gouda, H.N., F. Charlson, K. Sorsdahl, S. Ahmadzada, A.J. Ferrari, H. Erskine, J. Leung, J., et al. 2019. "Burden of Non-communicable Diseases in Sub-Saharan Africa, 1990-2017: Results from the Global Burden of Disease Study 2017." *The Lancet Global Health* 7 (10): e1375–e1387. https://doi.org/10.1016/s2214-109x(19)30374-2

Grace, D. 2014. "The Business Case for One Health." *Onderstepoort Journal of Veterinary Research* 81 (2): a725. http://dx.doi.org/10.4102/ojvr.v81i2.725

Havelaar, A.H., M.D. Kirk, P.R. Torgerson, H.J. Gibb, T. Hald, R.J. Lake, N. Praet et al. 2015. "World Health Organization Global Estimates and Regional Comparisons of the Burden of Foodborne Disease in 2010." *PLoS Med* 12 (12): e1001923. https://doi.org/10.1371/journal.pmed.1001923

Hayes, K., G. Blashki, J. Wiseman, S. Burke, and L. Reifels. 2018. "Climate Change and Mental Health: Risks, Impacts and Priority Actions." *International Journal of Mental Health Systems* 12: 28. https://doi.org/10.1186/s13033-018-0210-6

IPCC (Intergovernmental Panel on Climate Change). 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896

IPCC. 2014. Climate Change 2014. *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

Jagger, H., M. Mcdevette, S. Mutiga, T. Eldridge, P. Emmrich, D. Grace, S. Senay, A. Abate, R. Darnell, and A. Djikeng. 2016. "Poisoned Chalice: Toxin Accumulation in Crops in the Era of Climate Change." In *UNEP Frontiers 2016 Report: Emerging Issues of Environmental Concern*, 54-63. Nairobi, Kenya: United Nations Environment Programme (UNEP).

Justice, C.O., J.R.G. Townshend, B.N. Holben, and C.J. Tucker. 2002. "Analysis of the MODIS Land Cover Data for Land Surface Temperature and Vegetation Studies." *International Journal of Remote Sensing* 23 (3): 517–537. https://doi.org/10.1080/01431160110085299

Koua, E.L., J.R.N. Njingang, J.P. Kimenyi, G.S. Williams, J. Okeibunor, S. Oka,and A.S. Gueye. 2023. "Trends in Public Health Emergencies in the WHO African Region: An Analysis of the Past Two Decades Public Health Events from 2001 to 2022." *BMJ Global Health* 8 (10): e012015. https://doi.org/10.1136/bmjgh-2023-012015

Li, Z.-L., B.-H. Tang, H. Wu, H. Ren, G. Yan, Z. Wan, I.F. Trigo, and J.A. Sobrino, J. A. (2013). "Satellite-Derived Land Surface Temperature: Current Status and Perspectives." *Remote Sensing of Environment* 131: 14–37.

Li, Zhao-Liang, Bo-Hui Tang, Hua Wu, Huazhong Ren, Guangjian Yan, Zhengming Wan, Isabel F. Trigo, and José A. Sobrino. "Satellite-derived land surface temperature: Current status and perspectives." *Remote Sensing of Environment* 131 (2013): 14-37.

McIntyre, K.M., C. Setzkorn, P.J. Hepworth, S. Morand, A.P. Morse, and M. Baylis. 2017. "Systematic Assessment of the Climate Sensitivity of Important Human and Domestic Animals Pathogens in Europe." *Scientific Reports* 7 (1): 7134. https://doi.org/10.1038/s41598-017-06948-9

Mettenleiter, T.C., W. Markotter, D.F. Charron, W.B. Adisasmito, S. Almuhairi, C.B. Behravesh, P. Bilivogui, et al. 2023. "The One Health High-Level Expert Panel (OHHLEP)." *One Health Outlook* 5: 18. https://doi.org/10.1186/s42522-023-00085-2

Mora, C., T. McKenzie, I.M. Gaw, J.M. Dean, H. von Hammerstein, T.A. Knudson, R. O. Setter, et al. 2022. "Over Half of Known Human Pathogenic Diseases Can Be Aggravated by Climate Change." *Nature Climate Change* 12: 869–875. https://doi.org/10.1038/s41558-022-01426-1

Myers, J., T. Young, M. Galloway, P. Manyike, and T. Tucker. 2011. "A Public Health Approach to the Impact of Climate Change on Health in Southern Africa – Identifying Priority Modifiable Risks." *South African Medical Journal* 101 (11): 817–820.

NASA Earth Observatory. 2023. "Severe Drought in Southern Africa." February. https://earthobservatory.nasa.gov/images/152711/severe-drought-in-southern-africa

NISR (National Institute of Statistics of Rwanda). 2023. *Comprehensive Food Security and Vulnerability Analysis (CFSVA) 2021*. Kigali, Rwanda: NISR. https://microdata.statistics.gov.rw/index.php/catalog/106

Nugent, R., and E. Fottrell. 2019. "Non-communicable Diseases and Climate Change: Linked Global Emergencies." *The Lancet* 394 (10199): 622–623. https://doi.org/10.1016/s0140-6736(19)31762-3

O'Brien, Karen, S. Eriksen, L.P. Nygaard, and A.N.E. Schjolden. 2007. "Why Different Interpretations of Vulnerability Matter in Climate Change Discourses." *Climate Policy* 7 (1): 73–88. 10.3763/cpol.2007.0706.

O'Neill, B.C., C. Tebaldi, D.P. van Vuuren, V. Eyring, P. Friedlingstein, G. Hurtt, R. Knutti, et al. 2016. "The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6." *Geoscientific Model Development* 9 (9): 3461–3482. https://doi.org/10.5194/gmd-9-3461-2016

Okello, I., E. Mafie, G. Eastwood, J. Nzalawahe, and L.E.G. Mboera. 2022. "African Animal Trypanosomiasis: A Systematic Review on Prevalence, Risk Factors and Drug Resistance in Sub-Saharan Africa." *Journal of Medical Entomology* 59 (4): 1099–1143. https://doi.org/10.1093/jme/tjac018

Omazic, A., H. Bylund, S. Boqvist, A. Högberg, C. Björkman, M. Tryland, B. Evengård, et al. 2019. "Identifying Climate-Sensitive Infectious Diseases in Animals and Humans in Northern Regions." *Acta Veterinaria Scandinavica* 61 (1): 53. https://doi.org/10.1186/s13028-019-0490-0

PBL Netherlands Environmental Assessment Agency. 2018. *The Geography of Future Water Challenges*. The Hauge, Netherlands: PBL Netherlands Environmental Assessment Agency, The Hague.

Pettorelli, N., J.O. Vik, A. Mysterud, J.-M. Gaillard, C.J. Tucker, and N.C. Stenseth. 2005. "Using the Satellite-Derived Normalized Difference Vegetation Index (NDVI) to Assess Ecological Responses to Environmental Change." *Trends in Ecology & Evolution* 20 (9): 503-510. https://doi.org/10.1016/j.tree.2005.05.011

Sellers, S. 2020. "Cause of Death Variation under the Shared Socioeconomic Pathways." *Climatic Change* 163 (1): 559–577. https://doi.org/10.1007/s10584-020-02824-0

Semenza, J.C. 2020. "Cascading Risks of Waterborne Diseases from Climate Change." *Nature Immunology* 21 (5): 484–487. http://doi.org/10.1038/s41590-020-0631-7

Sharma, J. and N.H. Ravindranath. 2019. "Applying IPCC 2014 Framework for Hazard-Specific Vulnerability Assessment under Climate Change." *Environmental Research Communications* 1: 051004. https://iopscience.iop.org/article/10.1088/2515-7620/ab24ed/pdf

Smit, B., and O. Pilifosova. 2003. "Adaptation to Climate Change in the Context of Sustainable Development and Equity." *Sustainable Development* 8 (9): 9.

Suhr, F., and J.I. Steinert. 2022. "Epidemiology of Floods in Sub-Saharan Africa: A Systematic Review of Health Outcomes." *BMC Public Health* 22 (1): 268. https://doi.org/10.1186/s12889-022-12584-4

Taylor, K.E., R.J. Stouffer, and G.A. Meehl. 2012. "An Overview of CMIP5 and the Experiment Design." *Bulletin of the American Meteorological Society* 93 (4): 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Thomson, A.M., K.V. Calvin, S.J. Smith, G.P. Kyle, A. Volke, P. Patel, S. Delgado-Arias et al. 2011. "RCP4.5: A Pathway for Stabilization of Radiative Forcing by 2100." *Climatic Change* 109 (1): 77–94. https://doi.org/10.1007/s10584-011-0151-4

Thomson, M.C., Á.G. Muñoz, R. Cousin, and J. Shumake-Guillemot. 2018. "Climate Drivers of Vector-Borne Diseases in Africa and Their Relevance to Control Programmes." *Infectious Diseases of Poverty* 7: 81. https://doi.org/10.1186/s40249-018-0460-1

Tjaden, N.B., J.E. Suk, D. Fischer, S.M. Thomas, C. Beierkuhnlein, and J.C. Semenza. 2017. "Modelling the Effects of Global Climate Change on Chikungunya Transmission in the 21st Century." *Scientific Reports* 7: 3813. https://doi.org/10.1038/s41598-017-03566-3

UNDRR (United Nations Office for Disaster Risk Reduction). 2021. *GAR Special Report on Drought 2021*. Geneva.

UNEP (United Nations Environment Programme). 2020. *Preventing the Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission*. Nairobi, Kenya: UNEP.

UNICEF, WHO (World Health Organization), and World Bank. 2023. *Levels and Trends in Child Malnutrition: UNICEF/WHO/World Bank Group Joint Child Malnutrition Estimates*. New York: UNICEF; Geneva: WHO; Washington, DC: World Bank.

UNISDR (United Nations Office for Disaster Risk Reduction). 2015. *The Human Cost of Weather-Related Disasters: 1995-2015*. Geneva: UNISDR.

United Nations in South Africa. 2024. "Urgent Call to Action to Address Historic El Niño Drought in Southern Africa." June 6. https://southafrica.un.org/en/270894-urgent-call-action-address-historic-el-niño-drought-southern-africa

WFP (World Food Programme). 2023. *Drought in the Horn of Africa*. Rome: WFP. https://docs.wfp.org/api/documents/WFP-0000151188/download/

WHO (World Health Organization). 2014. *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*. Geneva: WHO.

World Bank. 2017. *Geographic Hotspots for World Bank Action on Climate Change and Health*. Washington, DC: World Bank. http://hdl.handle.net/10986/27810

Wu, M., and H. Lu. 2016. "A Modified Vegetation Water Supply Index (MVWSI) and its Application in Drought Monitoring over Sichuan and Chongqing, China." *Journal of Integrative Agriculture* 15 (9): 2132–2141. https://doi.org/10.1016/S2095-3119(15)61257-6

Yohe, G., and R.S.J. Tol. 2002. "Indicators for Social and Economic Coping Capacity—Moving toward a Working Definition of Adaptive Capacity." *Global Environmental Change* 12 (1): 25–40.

Chapter 6

Allen, L.H., B.A. Kimball, J.A. Bunce, M. Yoshimoto, Y. Harazono, J.T. Baker, K.J. Boote, and J.W. White. 2020. "Fluctuations of CO2 in Free-Air CO2 Enrichment (FACE) Depress Plant Photosynthesis, Growth, and Yield." Agricultural and Forest Meteorology 284: 107899. https://doi.org/10.1016/j.agrformet.2020.107899

Boogaard, H., J. Schubert, A. De Wit, J. Lazebnik, R. Hutjes, and G. Van der Grijn. 2022. "Agrometeorological Indicators from 1979 to Present Derived from Reanalysis, Version 1.0." Copernicus Climate Change Service (C3S) Climate Data Store (CDS). Last updated August 18, 2024. DOI: 10.24381/cds.6c68c9bb

DSSAT (Decision Support System for Agrotechnology Transfer). 2024. DSSAT model, Version 4.8.2. Last updated August 2023. www.DSSAT.net

FAO (Food and Agriculture Organization of the United Nations). 2022. FAOSTAT database. Accessed February 16, 2022. www.fao.org/faostat/en/#home

Hachigonta, S., G. Nelson, T.S. Thomas, and L.M. Sibanda, eds. 2013. Southern African Agriculture and Climate Change: A Comprehensive Analysis. Washington, DC: International Food Policy Research Institute (IFPRI). http://dx.doi.org/10.2499/9780896292086

Hoogenboom, G., C.H. Porter, K.J. Boote, V. Shelia, P.W. Wilkens, U. Singh, J.W. White, et al. 2019. "The DSSAT Crop Modeling Ecosystem." In Advances in Crop Modeling for a Sustainable Agriculture, ed. K.J. Boote, 173–216. Cambridge, UK: Burleigh Dodds Science Publishing. https://dx.doi.org/10.19103/AS.2019.0061.10

InTeGrate. 2018. "C3 and C4 Photosynthesis." Accessed August 30, 2024. https://serc.carleton.edu/integrate/teaching_materials/food_supply/student_materials/1167

International Labour Organization. 2024. "ILO modelled estimates database" ILOSTAT. Accessed February 07, 2024. ilostat.ilo.org/data

Jalloh, A., G.C. Nelson, T.S. Thomas, R. Zougmoré, and H. Roy-Macauley, eds. 2013. West African Agriculture and Climate Change: A Comprehensive Analysis. Washington, DC: IFPRI. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/127444

Jones, J.W., G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, et al. 2003. "The DSSAT Cropping System Model." European Journal of Agronomy 18 (3–4): 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7

Lange, S. 2021. ISIMIP3b Bias Adjustment Fact Sheet. Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). www.isimip.org/documents/413/ISIMIP3b_bias_adjustment_fact_sheet_Gnsz7CO.pdf

Li, P., C. Peng, M. Wang, W. Li, P. Zhao, K. Wang, Y. Yang, and Q. Zhu. 2017. "Quantification of the Response of Global Terrestrial Net Primary Production to Multifactor Global Change." Ecological Indicators 76: 245–255.

Nelson, G.C., J. Vanos, G. Havenith, O. Jay, K.L. Ebi, and R.J. Hijmans. 2024. "Global Reductions in Manual Agricultural Work Capacity Due to Climate Change." Global Change Biology 30 (1): e17142. https://doi.org/10.1111/gcb.17142

Robinson, S., S. Dunston, A. Mishra, T.B. Sulser, D. Mason-D'Croz, R.D. Robertson, N. Cenacchi, et al. 2024. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Documentation for Version 3.6. Modeling Systems Technical Paper 1. Washington, DC: IFPRI. https://hdl.handle.net/10568/148953

Rosegrant, M.W., T.B. Sulser, S. Dunston, A. Mishra, N. Cenacchi, Y. Gebretsadik, R. Robertson, T. Thomas, and K. Wiebe. 2024. "Food and Nutrition Security under Changing Climate and Socioeconomic Conditions." Global Food Security 41: 100755. https://doi.org/10.1016/j.gfs.2024.100755

Thomas, T.S., and R.D. Robertson. 2024. "Climate Change and Agriculture in Eastern and Southern Africa: An Updated Assessment Based on the Latest Global Climate Models." IFPRI Discussion Paper 2239. IFPRI, Washington, DC. https://cgspace.cgiar.org/items/2768dbfb-3800-4e3c-91d6-3cdf540feb9c

Thomas, T.S., R.D. Robertson, K. Strzepek, and C. Arndt. 2022. "Extreme Events and Production Shocks for Key Crops in Southern Africa Under Climate Change." Frontiers in Climate 4: 787582. https://doi.org/10.3389/fclim.2022.787582

Toreti, A., D. Deryng, F.N. Tubiello, C. Müller, B.A. Kimball, G. Moser, K. Boote, et al. 2020. "Narrowing Uncertainties in the Effects of Elevated CO2 on Crops." Nature Food 1: 775–782. https://doi.org/10.1038/s43016-020-00195-4

US Department of Energy. 2020. U.S. Department of Energy Free-Air CO2 Enrichment Experiments: FACE Results, Lessons, and Legacy. DOE/SC–0202. Washington, DC.

Waithaka, M., G. Nelson, T.S. Thomas, and M. Kyotalimye, eds. 2013. East African Agriculture and Climate Change: A Comprehensive Analysis. Washington, DC: IFPRI. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/127923

You, L., S. Wood, U. Wood-Sichra, and W. Wu. 2014. "Generating Global Crop Distribution Maps: From Census to Grid." Agricultural Systems 127: 53–60.

Zhu, C., J. Wolf, J. Zhang, W.R.L. Anderegg, J.A. Bunce, and L.H. Ziska. 2023. "Rising Temperatures Can Negate CO2 Fertilization Effects on Global Staple Crop Yields: A Meta-Regression Analysis." Agricultural and Forest Meteorology 342: 109737. https://doi.org/10.1016/j.agrformet.2023.109737

Chapter 7

ACBF (African Capacity Building Foundation). 2023. Coordination Challenges and Opportunities for Climate Adaptation in African Agriculture. Harare, Zimbabwe: ACBF.

Aina, I., O. Ayinde, D. Thiam, and M. Miranda. 2024. "Crop Index Insurance as a Tool for Climate Resilience: Lessons from Smallholder Farmers in Nigeria." *Natural Hazards* 120 (71): 4811–4828.

Al-Zu'bi, M., S.W. Dejene, J. Hounkpè, O.L. Kupika, S. Lwasa, M. Mbeng, C. Mwongera, N.S. Ouedraogo, and N.E. Touré. 2022. "African Perspectives on Climate Change Research." *Nature Climate Change* 12: 1078–1084.

Arslan, A., K. Floress, C. Lamanna, L. Lipper, and T.S. Rosenstock. 2022. "A Meta-analysis of the Adoption of Agricultural Technology in Sub-Saharan Africa." *PLOS Sustainability and Transformation* 1 (7): e0000018.

AU (African Union). 2023a. "African Integration Day 2023." July 7–9. https://au.int/sw/node/42898

AU. 2023b. *African Union Climate Change and Resilient Development Strategy and Action Plan (2022–2032).* Durban, South Africa: AU. https://au.int/sites/default/files/documents/41959-doc-CC_Strategy_and_Action_Plan_2022-2032_08_02_23_Single_Print_Ready.pdf

AU, CAADP, and AUDA-NEPAD. 2024. *4th CAADP Biennial Review Report 2015–2023.* Addis Ababa, Ethiopia. https://au.int/sites/default/files/documents/43556-doc-EN_4th_CAADP_Biennial_Review_Report-COMPLETE.pdf

Babatunde, E. O. "In the Light of Different National Circumstances: Equity under the Paris Agreement." *Cambridge Law Review* 4 (2): 105.

CPI (Climate Policy Initiative). 2022. *The State of Climate Finance in Africa: Climate Finance Needs of African Countries.* San Francisco: CPI. https://www.climatepolicyinitiative.org/publication/climate-finance-needs-of-african-countries/

Damptey, P.T.M., and S. Zakieldeen. 2020. "African Group of Negotiators (AGN)." In *Negotiating Climate Change Adaptation: The Common Position of the Group of 77 and China,* eds. M.D.P. Bueno Rubial and L. Siegele. Cham: Springer International Publishing.

Djido, A., R.B. Zougmoré, P. Houessionon, M. Ouédraogo, I. Ouédraogo, and N.S. Diouf. "To What Extent Do Weather and Climate Information Services Drive the Adoption of Climate-Smart Agriculture Practices in Ghana?" *Climate Risk Management* 32: 100309.

Elum, Z.A., and J.B. Simonyan. "Analysis of Nigerian Insurers' Perceptions of Climate Change." *South African Journal of Economic and Management Sciences* 19 (4): 549–561.

Epule, T.E., A. Chehbouni, D. Dhiba, M.W. Moto, and C. Peng. 2021. "African Climate Change Policy Performance Index." *Environmental and Sustainability Indicators* 12: 100163.

FAO (Food and Agriculture Organization of the United Nations). 2015. *RIMA-II: Moving Forward the Development of the Resilience Index Measurement and Analysis Model*. Rome: FAO. https://www.ipcinfo.org/fileadmin/user_upload/fsin/docs/RIMA-II_Brochure_ENG_v15.pdf

D'Souza, R., M. Jaspal, and S. Sengupta. 2022. *The Africa Climate Action Performance Report*. ORF Special Report No. 196. New Delhi: Observer Research Foundation.

Fenton, A., D. Gallagher, H. Wright, S. Huq, and C. Nyandiga. "Up-Scaling Finance for Community-Based Adaptation." *Climate and Development* 6 (4): 388–397.

Fonta, W.M., S. Sanfo, A.M. Kedir and D.R. Thiam. "Estimating Farmers' Willingness to Pay for Weather Index-Based Crop Insurance Uptake in West Africa: Insight from a Pilot Initiative in Southwestern Burkina Faso." *Agricultural and Food Economics* 6: 11(1), 1–20.

GCA (Global Center on Adaptation). 2022. *State and Trends in Adaptation Report 2022*. Rotterdam, the Netherlands: GCA.

Guzmán, S., G. Dobrovich, A. Balm, and C. Meattle. 2022. *The State of Climate Finance in Africa: Climate Finance Needs of African Countries*. San Francisco, CA: Climate Policy Initiative.

Hansen, J.W., L. Born, E.R. Dossou-Yovo, C. Mwongera, M.A. Dalaa, O. Tahidu, A.M. Whitbread. et al. 2022. "Country-Specific Challenges to Improving Effectiveness, Scalability and Sustainability of Agricultural Climate Services in Africa." *Frontiers in Climate* 4: 928512.

Hemingway Jaynes, C. 2023. "Climate Action: COP28 Agrees to Establish Loss and Damage Fund for Vulnerable Countries." *World Economic Forum* and *EcoWatch*, December 1. https://www.weforum.org/agenda/2023/12/cop28-loss-and-damage-fund-climate-change/

IFC (International Finance Corporation).2017. *Creating Markets for Climate Business an IFC Climate Investment Report*. Washington, DC: IFC.

IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate Change 2014. Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

Kelleher, A., and S. Mirpuri. 2023. "Behavior Change Is Key to Successful Climate Action Plans." Behavioural Insights Team [blog], October 30. https://www.bi.team/blogs/behavior-change-is-key-to-successful-climate-action-plans/

Kikstra, J.S., Z.R. Nicholls, C.J. Smith, J. Lewis, R.D. Lamboll, E. Byers, M. Sandstad, et al. 2022. "The IPCC Sixth Assessment Report WGIII Climate Assessment of Mitigation Pathways: From Emissions to Global Temperatures." *Geoscientific Model Development* 15 (24): 9075–9109.

Komarek, A.M., J. Thurlow, J. Koo, and A. De Pinto. 2019. "Economywide Effects of Climate-Smart Agriculture in Ethiopia." *Agricultural Economics* 50 (6): 765–778.

Leggett, J.A. 2021. "Climate Change: Defining *Adaptation* and *Resilience*, with Implications for Policy." CRS In Focus Report. Washington, DC: Congressional Research Service.

Mcleman, R., and B. Smit. 2006. "Vulnerability to Climate Change Hazards and Risks: Crop and Flood Insurance." *Canadian Geographies/ Géographies canadiennes* 50 (2): 217–226.

Mekonnen, A.F. 2019. *Zimbabwe: Agriculture Sector Disaster Risk Assessment*. Washington, DC: World Bank Group.

Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, D. Nelson et al. 2010. "Resilience and Vulnerability: Complementary or Conflicting Concepts?" *Ecology and Society* 15 (3): 11.

Ng'ang'a, S.K., M. Rivera, H. Pamuk, and J.P. Hella. 2020. "Costs and Benefits of Climate-Smart Agriculture Practices: Evidence from Intercropping and Crop Rotation of Maize with Soybean in Rural Tanzania." Working Paper No. 306. CGIAR, Wageningen, the Netherlands.

Nkonya, E., and J. Koo. 2017. "The Unholy Cross: Profitability and Adoption of Climate-Smart Agriculture Practices in Africa South of the Sahara." In *A Thriving Agricultural Sector in a Changing Climate: Meeting Malabo Declaration Goals through Climate-Smart Agriculture*, eds. A. De Pinto and J.M. Ulimwengu. Washington DC: International Food Policy Research Institute (IFPRI).

Ofoegbu, C. and M. New. 2022. "Evaluating the Effectiveness and Efficiency of Climate Information Communication in the African Agricultural Sector: A Systematic Analysis of Climate Services." *Agriculture* 12 (2): 160.

Ouedraogo, I., N.S. Diouf, G. Ablouka, R.B. Zougmoré, and A. Whitbread. 2021. "Utility and Triggers in Uptake of Agricultural Weather and Climate Information Services in Senegal, West Africa." *Atmosphere 12* (11): 1515.

Raithatha, R., and J. Priebe. 2020. *Agricultural Insurance for Smallholder Farmers: Digital Innovations for Scale*. London: GSMA.

Rwanda, Ministry of Agriculture and Animal Resources. 2022. *National Agricultural Insurance Scheme*. Kigali: Ministry of Agriculture and Animal Resources.

Sang, X., C. Chen, D. Hu, and D.B. Rahut. 2024. "Economic Benefits of Climate-Smart Agricultural Practices: Empirical Investigations and Policy Implications." *Mitigation and Adaptation Strategies for Global Change* 29: 9.

Shirley, R., Y. Deme, and S. Onyango. 2023. "Key COP28 Takeaways for Africa." *World Resources Institute*, December 20. https://www.wri.org/africa/key-cop28-takeaways-africa

Shumba, D.S. 2022. "Bundling Weather Index Insurance with Microfinance: Trekking the Long Road between Expectations and Reality–A Study on Sub-Saharan Africa." In *Food Systems Resilience*, eds. A.I. Ribeiro-Barros, D.S. Tevera, L.F. Goulao and L.D. Tivana. London: IntechOpen.

Signé, L. and A.A. Mbaye. 2022. "Renewing Global Climate Change Action for Fragile and Developing Countries." Global Economy & Development Working Paper 179. Brookings Institution, Washington, DC.

Tadesse, G., M. Tankari, I. Fofana, R. Ly, B. Sawadogo, and S. Koanda. 2024a. "Feasibility, Scalability and Ex-ante Impacts of Small-Scale Irrigation Technologies in Burkina Faso." AKADEMIYA2063 Working Paper Series No. 10. AKADEMIYA2063, Kigali, Rwanda. https://doi.org/10.54067/awps.010

Tadesse, G., M. Tankari, I. Fofana, R. Ly, S. Sangare, and B. Ousseini. 2024b. "Feasibility, Scalability and Ex-ante Impacts of Small-Scale Irrigation Technologies in Niger." AKADEMIYA2063 Working Paper Series No. 11. AKADEMIYA2063, Kigali, Rwanda.

Tiwari, S., S. Daidone, M.A. Ruvalcaba, E. Prifti, S. Handa, B. Davis, O. Niang, L. Pellerano, P.Q. van Ufford, and D. Seidenfeld. 2016. "Impact of Cash Transfer Programs on Food Security and Nutrition in Sub-Saharan Africa: A Cross-Country Analysis." *Global Food Security* 11: 72–83.

UNECA (United Nations Economic Commission for Africa). 2013. *Vulnerability to Climate Change in Africa Challenges and Recommendations for Africa*. ClimDev Africa Policy Brief. Addis Ababa: UNECA.

USAID (United States Agency for International Development). 2019. *Integrating Social and Behavior Change in Climate Change Adaptation: An Introductory Guide*. Washington, DC: USAID. https://www.climatelinks.org/sites/default/files/asset/document/2019_USAID_ATLAS_SBC%20Guide.pdf

Weber, E.J. 2019. "Weather Index Insurance in Sub-Saharan Africa." Economics Discussion Papers No. 19.03. University of Western Australia, Perth, Australia. https://research-repository.uwa.edu.au/files/96622610/DP19.03_Weber.pdf

Williams, P.A., N.P. Simpson, E. Totin, M.A. North, and C.H. Trisos. 2021. "Feasibility Assessment of Climate Change Adaptation Options across Africa: An Evidence-Based Review." *Environmental Research Letters* 16 (7): 073004.

World Bank. 2011. "The Weather Index i-Insurance for Agriculture: Guidance for Development Practitioners." Agriculture and Rural Development Discussion Paper 50. World Bank, Washington, DC.

WMO (World Meteorological Organization). 2020. *The State of the Climate in Africa 2019*. Geneva: WMO.

Zolnikov, T.R. 2019. "The World Adapting to Climate Change." In *Global Adaptation and Resilience to Climate Change*, ed. T.R. Zolnikov, 117–132. Cham, Switzerland: Palgrave Macmillan.

Chapter 8

Abasubong, K.P., N.N. Gabriel, J-J.Y. Adjoumani, and A.O. Okon. 2023. "Waste to Feed: An Emerging Technology to Improve Aquaculture in Africa." In *Emerging Sustainable Aquaculture Innovations in Africa,* eds. N.N. Gabriel, E. Omoregie, and K.P. Abasubong, 103–130. Singapore: Springer Singapore.

Abe-Inge, V., and E.M. Kwofie. 2023. "Accounting for Environmental-Nutrition Trade-offs in African Food Systems." In *Empowering Africa's Food Systems for the Future*, ed. S. Maina, 143–162. Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).

Adepoju, O.T., and A.O. Ayenitaju. 2021. "Assessment of Acceptability and Nutrient Content of Palm Weevil (*Rhyncophorus phoenicis*) Larvae Enriched Complementary Foods." *International Journal of Tropical Insect Science* 41: 2263–2276. http://doi.org/10.1007/s42690-021-00487-7

Adeyeye, S.A.O., A.O. Adebayo-Oyetoro, and H.K. Tiamiyu. 2017. "Poverty and Malnutrition in Africa: A Conceptual Analysis." *Nutrition & Food Science* 47 (6): 754–764. http://doi.org/10.1108/nfs-02-2017-0027

Africa Business Page. 2022. "The Plastics Industry in Africa." Accessed May 20, 2023. https://africa-business.com/features/plastics.html

AU (African Union). 2023. "Scaling Up the Access to Biofortified Seeds to Address Malnutrition in Africa." African Union Press Release, October 9. https://au.int/en/pressreleases/20231009/scaling-access-biofortified-seeds-address-malnutrition-africa

AgriSA. 2023. "AgriSA Secures an Inclusive and Prosperous Agriculture Sector." Accessed June 1, 2023. https://agrisa.co.za/

Aidoo, R., E.M. Kwofie, P. Adewale, E. Lam, and M. Ngadi. 2023. "Overview of Single Cell Protein: Production Pathway, Sustainability Outlook, and Digital Twin Potentials." *Trends in Food Science & Technology* 138: 577–598. http://doi.org/10.1016/j.tifs.2023.07.003

Aidoo, R., E.M. Kwofie, P. Adewale, E. Lam, and M. Ngadi. 2024. "Designing Sustainable Circular Bioeconomy Solutions for the Pulse Industry: The Case of Crude Pea Starch as a Substrate for Single Cell Protein Production." *Science of the Total Environment* 912: 169029. http://doi.org/10.1016/j.scitotenv.2023.169029

Aidoo, R., E.M. Kwofie, and M.O. Ngadi. 2022. "Circularity of Cashew Apples: Examining the Product-Process Pathways, Techno-functional, Nutritional/Phytomolecular Qualities for Food Applications." *ACS Food Science & Technology* 2 (7): 1051–1066. http://doi.org/10.1021/acsfoodscitech.2c00093

Akutse, K.S., S. Subramanian, N.K. Maniania, T. Dubois, and S. Ekesi. 2020. "Biopesticide Research and Product Development in Africa for Sustainable Agriculture and Food Security – Experiences from the International Centre of Insect Physiology and Ecology (ICIPE)." *Frontiers in Sustainable Food Systems* 4: 563016. http://doi.org/10.3389/fsufs.2020.563016

Akyereko, Y.G., G.B. Yeboah, F.D. Wireko-Manu, F. Alemawor, F. C. Mills-Robertson, and W. Odoom. 2023. "Nutritional Value and Health Benefits of Cashew Apple." *JSFA Reports* 3, 3: 110–118. https://doi.org/10.1002/jsf2.107

Ashaolu, C.A., C. Okonkwo, E. Njuguna, and D. Ndolo. 2021. "Recommendations for Effective and Sustainable Regulation of Biopesticides in Nigeria." *Sustainability* 14 (5): 2846. http://doi.org/10.3390/su14052846

Atowa, C.O., B.C. Okoro, E.C. Umego, A.O. Atowa, O. Emmanuel, V.C. Ude, and E.A. Ugbogu. 2021. "Nutritional Values of *Zonocerus variegatus*, *Macrotermes Bellicosus* and *Cirina forda* Insects: Mineral Composition, fatty Acids and Amino Acid Profiles." *Scientific African* 12: e00798. http://doi.org/10.1016/j.sciaf.2021.e00798

Awobusuyi, T.D., M. Siwela, and K. Pillay. 2021. "Nutritional Composition of Insect Types Most Commonly Consumed by The Olugboja Community of Ondo State, Nigeria." *International Journal of Tropical Insect Science* 41**:** 2975–2982. http://doi.org/10.1007/s42690-021-00483-x

Bationo, F., B. Savadogo, and M. Goubgou. 2022. "Folates in Various African Foods: Contents, Food Processing and Matrix Effects." *International Journal for Vitamin and Nutrition Research* 93 (5): 459–470. http://doi.org/10.1024/0300-9831/a000759

Benjamin, E.O., D. Tzemi, and D.S. Fialho. 2021. "Sustainable Urban Farming in Sub-Saharan Africa: A Review of a Coupled Single-Loop Aquaponics System in Nigeria." *Preprints* 2021110372. https://doi.org/10.20944/preprints202111.0372.v1

Berardy, A., C.S. Johnston, A. Plukis, M. Vizcaino, and C. Wharton. 2019. "Integrating Protein Quality and Quantity with Environmental Impacts in Life Cycle Assessment." *Sustainability* 11 (10): 2747. http://doi.org/10.3390/su11102747

Bessa, L., A. Olayemi, and B. Monthe. 2021. "Turning Africa's Food Waste Problem into a Regenerative Opportunity." *Climate Champions News,* October 25. Available: https://climatechampions.unfccc.int/turning-africas-food-waste-problem-into-a-regenerative-opportunity/

Boon, E.K., and S.W. Anuga. 2020. "Circular Economy and Its Relevance for Improving Food and Nutrition Security in Sub-Saharan Africa: The Case of Ghana." *Materials Circular Econom,* 2: 5. http://doi.org/10.1007/s42824-020-00005-z

Boxman, S.E., Q. Zhang, D. Bailey, and M.A. Trotz. 2017. "Life Cycle Assessment of a Commercial-Scale Freshwater Aquaponic System." *Environmental Engineering Science* 34 (5): 299–311. http://doi.org/10.1089/ees.2015.0510

Callo-Concha, D., H. Jaenicke, C.B. Schmitt, and M. Denich, eds. 2020a. *Advances in Food and Non-food Biomass Production, Processing and Use in Sub-Saharan Africa: Towards a Basis for a Regional Bioeconomy.* Basel, Switzerland: MDPI.20. Callo-Concha, D., H. Jaenicke, C.B. Schmitt, and M. Denich. 2020b. "Food and Non-food Biomass Production, Processing and Use in Sub-Saharan Africa: Towards a Regional Bioeconomy." *Sustainability* 12 (5): 2013.

Chakravarthy, A.K., G.T. Jayasimha, R.R. Rachana, and G. Rohini. 2016. "Insects as Human Food." In *Economic and Ecological Significance of Arthropods in Diversified Ecosystems: Sustaining Regulatory Mechanisms,* eds. A.K. Chakravarthy and S. Sridhara, 133–146. Singapore: Springer Singapore.

Chakravorty, J., S. Ghosh, K. Megu, C. Jung, and V.B. Meyer-Rochow. 2016. "Nutritional and Anti-nutritional Composition of *Oecophylla smaragdina* (Hymenoptera: Formicidae) and *Odontotermes* sp. (Isoptera: Termitidae): Two Preferred Edible Insects of Arunachal Pradesh, India." *Journal of Asia-Pacific Entomology* 19 (3): 711–720. http://doi.org/10.1016/j.aspen.2016.07.001

Chen, P., G. Zhu, H-J. Kim, P.B. Brown, and J-Y. Huang. 2020. "Comparative Life Cycle Assessment of Aquaponics and Hydroponics in the Midwestern United States." *Journal of Cleaner Production* 275: 122888. http://doi.org/10.1016/j.jclepro.2020.122888

Chesoli, R.N., M. Sartas, T. Muzhingi, and O. Emanuel. 2024. "Application of the Scaling Readiness Approach for Scaling of Nutrition-Sensitive Initiatives in Kenya, Uganda, and Malawi: A Case of Orange Fleshed Sweetpotato Value Chain." *Crop Science* 64 (3): 1517–1524. https://doi.org/10.1002/csc2.21053

Christian, A.K., and F.A.A. Dake. 2022. "Profiling Household Double and Triple Burden of Malnutrition in Sub-Saharan Africa: Prevalence and Influencing Household Factors." *Public Health Nutrition* 25 (6): 1563–1576. http://doi.org/10.1017/S1368980021001750

D'amato, D., and J. Korhonen. 2021. "Integrating the Green Economy, Circular Economy and Bioeconomy in a Strategic Sustainability Framework." *Ecological Economics* 188: 107143. http://doi.org/10.1016/j.ecolecon.2021.107143

D'amato, D., S. Veijonaho, and A. Toppinen. 2020. "Towards Sustainability? Forest-based Circular Bioeconomy Business Models in Finnish SMEs." *Forest Policy and Economics* 110: 101848. http://doi.org/10.1016/j.forpol.2018.12.004

Das, A.K., P.K. Nanda, P. Dandapat, S. Bandyopadhyay, P. Gullon, G.K. Sivaraman, D.J. Mcclements, B. Gullon, and J.M. Lorenzo. 2021. "Edible Mushrooms as Functional Ingredients for Development of Healthier and More Sustainable Muscle Foods: A Flexitarian Approach." *Molecules* 26 (9): 2463. http://doi.org/10.3390/molecules26092463

Das, I., and A. Arora. 2017. "Post-harvest Processing Technology for Cashew Apple–A Review." *Journal of Food Engineering,* 194: 87–98.

Delisle, H., M. Faber, and P. Revault. 2021. "Evidence-based Strategies Needed to Combat Malnutrition in Sub-Saharan Countries Facing Different Stages of Nutrition Transition. *Public Health Nutrition* 24 (12): 3577–3580. http://doi.org/10.1017/s1368980021001221

Dessie, G., J. Li, S. Nghiem, and T. Doan. 2024. "Prevalence and Determinants of Stunting-Anemia and Wasting-Anemia Comorbidities and Micronutrient Deficiencies in Children under 5 in the Least-Developed Countries: A Systematic Review and Meta-analysis." *Nutrition Reviews* 2024: nuae063. https://doi.org/10.1093/nutrit/nuae063

Dimopoulou, M., A. Kolonas, S. Mourtakos, O. Androutsos, and O. Gortzi. 2022. "Nutritional Composition and Biological Properties of Sixteen Edible Mushroom Species." *Applied Sciences* 12 (6): 8074. http://doi.org/10.3390/app12168074

Dimoso, N., A. Aluko, E. Makule, and N. Kassim. 2020. "Challenges and Opportunities Toward Sustainable Consumption and Value Addition of Cashew Apples in Tanzania." *Outlook on Agriculture* 50 (2): 169–177. http://doi.org/10.1177/0030727020941164

Dorr, E., M. Koegler, B. Gabrielle, and C. Aubry. 2021. "Life Cycle Assessment of a Circular, Urban Mushroom Farm." *Journal of Cleaner Production* 288: 125668. http://doi.org/10.1016/j.jclepro.2020.125668

Dzepe, D., H.M. Kuietche, O. Magatsing, F. Meutchieye, P. Nana, T. Tchuinkam, and R. Djouaka. 2023. "From Agricultural Waste to Chicken Feed Using Insect-based Technology." *The Journal of Basic and Applied Zoology* 84: 18. http://doi.org/10.1186/s41936-023-00339-5

East African Community 2022. "The East African Regional Bioeconomy Strategy." Paper presented at the *1st East Africa Bioeconomy Conference*, Nairobi, Kenya.

Ekun, V.S., C.O. Adenipekun, O. Idowu, and P.M. Etaware. 2021. "Biotransformation of Agro-industrial Waste to Wealth in Africa through Mushroom Farming." BioRxiv preprint. http://doi.org/10.1101/2021.03.01.433330

Elemo, B.O., G.N. Elemo, M.A. Makinde, and O.L. Erukainure. 2011. "Chemical Evaluation of African Palm Weevil, *Rhychophorus phoenicis*, Larvae as a Food Source." *Journal of Insect Science* 11 (1): 146. http://doi.org/10.1673/031.011.14601

Elnour, M., H. Haller, and M. Martin. 2023. "Life Cycle Assessment of a Retail Store Aquaponic System in a Cold-Weather Region." *Frontiers in Sustainability* 3: 1051091. http://doi.org/10.3389/frsus.2022.1051091

Engidaw, M.T., A.D. Gebremariam, S.A. Tiruneh, D. Tesfa, Y. Fentaw, B. Kefale, M. Tiruneh, and A.T. Wubie. 2023. "Micronutrient Intake Status and Associated Factors in Children Aged 6–23 Months in Sub-Saharan Africa." *Scientific Reports* 13: 10179. http://doi.org/10.1038/s41598-023-36497-3

Espinosa-Salas, S., and M. Gonzalez-Arias. 2023 *Nutrition: Macronutrient Intake, Imbalances, and Interventions*. Treasure Island, FL: StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK594226/

Eyayu, A., A. Getahun, and J.L. Keyombe. 2023. "A Review of the Production Status, Constraints, and Opportunities in East African Freshwater Capture and Culture Fisheries." *Aquaculture International* 31: 2057–2078. http://doi.org/10.1007/s10499-023-01071-1

Eyinla, T.E., B. Maziya-Dixon, O.E. Alamu, and R.A. Sanusi. 2019. "Retention of Pro-vitamin a Content in Products from New Biofortified Cassava Varieties." *Foods* 8 (5): 177. http://doi.org/10.3390/foods8050177

FAO (Food and Agriculture Organization of the United Nations). 2022. *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*. Rome: FAO. https://doi.org/10.4060/cc0461en

FAO. 2024. "Technical Platform on the Measurement and Reduction of Food Loss and Waste." Accessed April 12, 2024. https://www.fao.org/platform-food-loss-waste/flw-data/en

FAO. 2018. *Sustainable Food Systems: Concept and Framework*. Rome: FAO. https://www.fao.org/3/ca2079en/CA2079EN.pdf

Feleke, S., S.M. Cole, H. Sekabira, R. Djouaka, and V. Manyong. 2021. "Circular Bioeconomy Research for Development in Sub-Saharan Africa: Innovations, Gaps, and Actions." *Sustainability* 13 (4): 1926. http://doi.org/10.3390/su13041926

Ferrari, L., S.A. Panaite, A. Bertazzo, and F. Visioli. 2022. "Animal- and Plant-based Protein Sources: A Scoping Review of Human Health Outcomes and Environmental Impact." *Nutrients* 14 (23): 5115. http://doi.org/10.3390/nu14235115

Foodstruct. n.d. "Encyclopedia of Food and Nutrition Focused on Comparison." Accessed April 20, 2024. https://foodstruct.com/

Fulgoni III, V.L., and S. Agarwal. 2021. "Nutritional Impact of Adding a Serving of Mushrooms on Usual Intakes and Nutrient Adequacy Using National Health and Nutrition Examination Survey 2011–2016 Data." *Food Science & Nutrition* 9 (3): 1504–1511. http://doi.org/10.1002/fsn3.2120

Ganvir, K.P., A.N. Darvekar, V.D. Raut, and R.K. Thorat. 2022. "Effect of Locally Generated Food Waste on Bioconversion and Nutrient Parameters of Black Soldier Fly Larvae, *Hermetia illucens* L." *Journal of Entomology and Zoology Studies* 10 (5): 108–116. http://doi.org/10.22271/j.ento.2022.v10.i6b.909

Gargano, M.L., G.I. Zervakis, O.S. Isikhuemhen, G. Venturella, R. Calvo, A. Giammanco, T. Fasciana, and V. Ferraro. 2020. "Ecology, Phylogeny, and Potential Nutritional and Medicinal Value of a Rare White "Maitake" Collected in a Mediterranean Forest." *Diversity* 12 (6): 230. http://doi.org/10.3390/d11060230

Gashaw, G., and A. Getu. 2020. "Evaluation of Antifungal Activity of Pleurotus Species Cultivated on Different Agricultural Wastes in Chiro, Ethiopia." *Asian Journal of Dairy and Food Research* 39 (4): 349–353. http://doi.org/10.18805/ajdfr.DR-165

Gatune, J., N. Ozor, and R. Oriama. 2021. "Modelling Bioeconomy Futures for Eastern Africa." *Foresight* 23**:** 226–241. http://doi.org/10.1108/fs-03-2020-0032

Gebremedhin, S. 2021. "Trends in Vitamin B12 Supply and Prevalence of Inadequate Intake in Africa: Regional and Country-Specific Estimates." *Food and Nutrition Bulletin* 42: 467–479. http://doi.org/10.1177/03795721211043353

Ghamkhar, R., C. Hartleb, Z. Rabas, and A. Hicks. 2022. "Evaluation of Environmental and Economic Implications of a Cold-Weather Aquaponic Food Production System Using Life Cycle Assessment and Economic Analysis." *Journal of Industrial Ecology* 26: 862–874. http://doi.org/10.1111/jiec.13230

Gillespie, S., M. van den Bold, J. Hodge, and A. Herforth. 2015. "Leveraging Agriculture for Nutrition in South Asia and East Africa: Examining the Enabling Environment through Stakeholder Perceptions." *Food Security* 7: 463–477. https://doi.org/10.1007/s12571-015-0449-6

Githanga, D., A. Awiti, F. Were, T. Ngwiri, M.Y. Nyarko, and N. Shellack. 2019. "A Consensus on Malnutrition in Africa: A Report from the Micronutrient Deficiency Awareness Forum (Nairobi 2017)." *African Journal of Food, Agriculture, Nutrition and Development* 19 (2): 14277–14290. http://doi.org/10.18697/ajfand.85.17775

Global Hunger Index. 2023. "Global, Regional and National Trends." Accessed May 12, 2024. https://www.globalhungerindex.org/trends.html

Global Market Insights. 2022. *Edible Insects Market Size by Product (Beetles, Caterpillars, Grasshoppers, Bees, Wasps, Ants, Scale Insects & Tree Bugs), by Application (Flour, Protein Bars, Snacks), Industry Analysis Report, Regional Outlook, Application Potential Price Trends, Competitive Market Share & Forecast, 2020–2026*. Selbyville, DE: Global Market Insights. https://www.gminsights.com/industry-analysis/edible-insects-market

Globefish. 2024. “Information and Analysis on Markets and Trade of Fisheries and Aquaculture Products.” Accessed April 19, 2024. https://www.fao.org/in-action/globefish/fishery-information/resource-detail/en/c/338418/

Go Green Aquaponics. 2024. “What Is Aquaponics and How Does It Work?” *Go Green Aquaponics Blog,* June 29. https://gogreenaquaponics.com/blogs/news/what-is-aquaponics-and-how-does-it-work

Gooding, C., S. Musa, T. Lavin, L. Sibeko, C.M. Ndikom, S. Iwuagwu, M. Ani-Amponsah, A.N. Maduforo, and B. Salami. 2024. “Nutritional Challenges among African Refugee and Internally Displaced Children: A Comprehensive Scoping Review.” *Children* 11 (3): 318. https://doi.org/10.3390/children11030318

Grabowski, N.T., S. Tchibozo, A. Abdulmawjood, F. Acheuk, M. M’saad Guerfali, W.A.A. Sayed, and M. Plötz. 2020. “Edible Insects in Africa in Terms of Food, Wildlife Resource, and Pest Management Legislation.” *Foods* 9 (4): 502. https://doi.org/10.3390/foods9040502

Greenfeld, A., N. Becker, J.F. Bornman, S. Spatari, and D.L. Angel. 2022. “Is Aquaponics Good For the Environment?—Evaluation of Environmental Impact through Life Cycle Assessment Studies on Aquaponics Systems.” *Aquaculture International* 30: 305–322. http://doi.org/10.1007/s10499-021-00800-8

Guldan, G.S. 2020. “Undernutrition and Overnutrition: The Challenging Double Burden of Malnutrition.” In *Good Health and Well-Being*, eds. W.L. Filho, T. Wall, A.M. Azul, L. Brandli, and P.G. Özuyar, 747–759. Cham, Switzerland: Springer Nature.

Gunady, M.G., W. Biswas, V.A. Solah, and A.P. James. 2012. “Evaluating the Global Warming Potential of the Fresh Produce Supply Chain for Strawberries, Romaine/Cos Lettuces (*Lactuca sativa*), and Button Mushrooms (*Agaricus bisporus*) in Western Australia Using Life Cycle Assessment (LCA).” *Journal of Cleaner Production* 28: 81–87. https://doi.org/10.1016/j.jclepro.2011.12.031

Gundoshmian, T.M., S. Ardabili, M. Csaba, and A. Mosavi. 2022. “Modeling and Optimization of the Oyster Mushroom Growth Using Artificial Neural Network: Economic and Environmental Impacts.” *Mathematical Biosciences and Engineering* 19 (10): 9749–9768. http://doi.org/10.3934/mbe.2022453

Halloran, A., Y. Hanboonsong, N. Roos, and S. Bruun. 2017. “Life Cycle Assessment of Cricket Farming in North-eastern Thailand.” *Journal of Cleaner Production* 156: 83–94. http://doi.org/10.1016/j.jclepro.2017.04.017

Hamadeh, N., C.V. Rompaey, E. Metreau. 2023. “World Bank Group Country Classifications by Income Level for Fy24 (July 1, 2023–June 30, 2024).” *World Bank Blogs*, June 30. https://blogs.worldbank.org/en/opendata/new-world-bank-group-country-classifications-income-level-fy24

Hindelang, M., Gheewala, S. H., Mungkung, R. & Bonnet, S., 2014. “Environmental Sustainability Assessment of a Media Based Aquaponics System in Thailand.” *Journal of Sustainable Energy & Environment* 5: 109–116.

Hlongwane, Z.T., R. Slotow, and T.C. Munyai. 2020. “Nutritional Composition of Edible Insects Consumed in africa: A Systematic Review.” *Nutrients* 12 (9): 2786. http://doi.org/10.3390/nu12092786

Hlongwane, Z.T., R. Slotow, and T.C. Munyai. 2021. “Indigenous Knowledge about Consumption of Edible Insects in South Africa.” *Insects* 12 (1): 22. https://doi.org/10.3390%2Finsects12010022

Hodge, J., A. Herforth, S. Gillespie, M. Beyero, M. Wagah, and R. Semakula. 2015. “Is There an Enabling Environment for Nutrition-Sensitive Agriculture in East Africa? Stakeholder Perspectives from Ethiopia, Kenya, and Uganda.” *Food and Nutrition Bulletin* 36 (4): 503–519. https://doi.org/10.1177/0379572115611289

Hollmann, R.E. 2017. *An Aquaponics Life Cycle Assessment: Evaluating an Innovative Method for Growing Local Fish and Lettuce*. Denver, CO: University of Colorado.1369738560

Huffman, S.L., R.K. Harika, A. Eilander, and S.J. Osendarp. 2011. “Essential Fats: How do They Affect Growth and Development of Infants and Young Children in Developing Countries? A Literature Review.” *Maternal and Child Nutrition* 7 (s3): 44–65. http://doi.org/10.1111/j.1740-8709.2011.00356.x

Ibarra-Herrera, C.C., B. Acosta-Estrada, C. Chuck-Hernández, S.N.Serrano-Sandoval, D. Guardado-Félix, and E. Pérez-Carrillo. 2020. “Nutritional Content of Edible Grasshopper (*Sphenarium purpurascens*) Fed on Alfalfa (*Medicago sativa*) and Maize (*Zea mays*).” *CyTA - Journal of Food* 18: 257–263. http://doi/org/10.1080/19476337.2020.1746833

Jeyavishnu, K., D. Thulasidharan, M.F. Shereen, and A. Arumugam. 2021. “Increased Revenue with High Value-Added Products from Cashew Apple (*Anacardium occidentale* L.)—Addressing Global Challenges.” *Food and Bioprocess Technology* 14: 985–1012. http://doi.org/10.1007/s11947-021-02623-0

Joy, E.J.M., E.L. Ander, S.D. Young, C.R. Black, M.J. Watts, A.D.C. Chilimba, B. Chilima, et al. 2014. "Dietary Mineral Supplies in Africa." *Physiologia Plantarum* 151 (3): 208–229. https://doi.org/10.1111/ppl.12144

Kababu, M., C.K. Mweresa, S. Subramanian, J.P. Egonyu, and C.M. Tanga. 2023. "Variability in Nutrient Composition of the Edible Long-horned Grasshopper (*Ruspolia differens*) in Uganda and Its Potential in Alleviating Food Insecurity." *Food Science & Nutrition* 11 (6): 3558–3574. http://doi.org/10.1002/fsn3.3346

Kaleem, O., and A-F. Bio Singou Sabi. 2021. "Overview of Aquaculture Systems in Egypt and Nigeria, Prospects, Potentials, and Constraints." *Aquaculture and Fisheries* 6 (6): 535–547. https://doi.org/10.1016/j.aaf.2020.07.017

Kavle, R.R., E.T.M. Pritchard, A. Carne, A.E-D.A. Bekhit, J.D. Morton, and D. Agyei. 2023. "Nutritional Composition and Techno-functional Properties of Sago Palm Weevil (*Rhynchophorus ferrugineus*) Larvae Protein Extract." *Journal of Asia-Pacific Entomology* 26 (2): 102086. http://doi.org/10.1016/j.aspen.2023.102086

Kelemu, S., S. Niassy, B. Torto, K. Fiaboe, H. Affognon, H. Tonnang, N.K. Maniania, and S. Ekesi. 2015. "African Edible Insects for Food and Feed: Inventory, Diversity, Commonalities and Contribution to Food Security." *Journal of Insects as Food and Feed* 1 (2): 103–120. https://doi.org/10.3920/JIFF2014.0016

Kihara, J., P. Bolo, M. Kinyua, J. Rurinda, and K. Piikki. 2020. "Micronutrient Deficiencies in African Soils and the Human Nutritional Nexus: Opportunities with Staple Crops." *Environmental Geochemistry and Health* 42: 3015–3033. http://doi.org/10.1007/s10653-019-00499-w

Kinyuru, J.N., S.O. Konyole, N. Roos, C.A. Onyango, V.O. Owino, B.O. Owuor, B.B. Estambale, H. Friis, J. Aagaard-Hansen, and G.M. Kenji. 2013. "Nutrient Composition of Four Species of Winged Termites Consumed in Western Kenya." *Journal of Food Composition and Analysis* 30 (2): 120–124. http://doi.org/10.1016/j.jfca.2013.02.008

Kohutek, F., J. Homolova, and B. Bystricky. 2024. "138P Do Overweight, Obesity and Nutritional Status Affect Survival Rates in Colorectal Cancer Treated with Systemic Treatment: An AI-driven Retrospective Study." *Annals of Oncology* 35 (S1): S63. https://doi.org/10.1016/j.annonc.2024.05.148

Kolobe, S.D., T.G. Manyelo, E. Malematja, N.A. Sebola, and M. Mabelebele. 2023. "Fats and Major Fatty Acids Present in Edible Insects Utilised as Food and Livestock Feed." *Veterinary and Animal Science* 22: 100312. https://doi.org/10.1016/j.vas.2023.100312

Kortei, N.K., V.P. Dzogbefia, and M. Obodai. 2014. "Assessing the Effect of Composting Cassava Peel Based Substrates on the Yield, Nutritional Quality, and Physical Characteristics of *Pleurotus ostreatus* (Jacq. Ex Fr.) Kummer." *Biotechnology Research International* 2014: 571520. http://doi.org/10.1155/2014/571520

Kumla, J., N. Suwannarach, K. Sujarit, W. Penkhrue, P. Kakumyan, K. Jatuwong, S. Vadthanarat, and S. Lumyong. 2020. "Cultivation of Mushrooms and Their Lignocellulolytic Enzyme Production through the Utilization of Agro-industrial Waste." *Molecules* 25 (12): 2811. https://doi.org/10.3390/molecules25122811

Kusumaningtyas, R., R. Wulansarie, W. Astuti, N. Hartini, and S. Richana. 2020. "Community Empowerment on the Biopesticide Production from Durian Peel Waste." Paper presented at the *5th International Conference on Science, Education and Technology, ISET 2019,* 29th June 2019, Semarang, Central Java, Indonesia.

Lamponi, S. 2021. "The Importance of Structural and Functional Analysis of Extracts in Plants." *Plants* 10, 6: 1225. https://doi.org/10.3390/plants10061225

Liceaga, A.M. 2021. "Processing Insects for Use in the Food and Feed Industry." *Current Opinion in Insect Science* 48: 32–36. http://doi.org/10.1016/j.cois.2021.08.002

Linda, G., A. Mohamed Tawfic, G. Kidane Giday, H.Y.K. Jamidu, O. Suzan, O. Oladele, R. Ulf Henning, and H.Y. Arsène. 2019. "Solid Waste Management in Africa: Governance Failure or Development Opportunity?" In *Regional Development in Africa,* ed. E. Norbert. Rijeka, Croatia: IntechOpen.

Lokeshkumar, V., B.A. Daniel, J. Jayanthi, and M.G. Ragunathan. 2022. "Nutritive Evaluations of Laboratory-reared Edible Field Cricket *Coiblemmus compactus* Chopard, 1928 (Orthoptera: Gryllidae), for Utilising Them as an Alternate Protein Source." *The Journal of Basic and Applied Zoology* 83: 26. http://doi.org/10.1186/s41936-022-00289-4

Lowe, N.M. 2021. "The Global Challenge of Hidden Hunger: Perspectives from the Field." *Proceedings of the Nutrition Society* 80 (3): 283–289. http://doi.org/10.1017/s0029665121000902

Lundy, M.E., and M.P. Parrella. 2015. "Crickets are Not a Free Lunch: Protein Capture from Scalable Organic Side-Streams via High-Density Populations of *Acheta domesticus*." *PLoS ONE,* 10 (4): e0118785. http://doi.org/10.1371/journal.pone.0118785

Madau, F.A., B. Arru, R. Furesi, and P. Pulina. 2020. "Insect Farming for Feed and Food Production from a Circular Business Model Perspective." *Sustainability* 12 (13): 5418. http://doi.org/10.3390/su12135418

Magingo, F.S., N.M. Oriyo, A.K. Kivaisi, and E. Danell. 2004. "Cultivation of *Oudemansiella tanzanica* nom. prov. on Agricultural Solid Wastes in Tanzania." *Mycologia* 96 (2): 19–-204. https://doi.org/10.1080/15572536.2005.11832967

Mak, T.M.W., X. Xiong, D.C.W. Tsang, I.K.M. Yu, and C.S. Poon. 2020. "Sustainable Food Waste Management towards Circular Bioeconomy: Policy Review, Limitations and Opportunities." *Bioresource Technology* 297: 122497. https://doi.org/10.1016/j.biortech.2019.122497

Makkar, H.P.S., G. Tran, V. Heuzé, and P. Ankers. 2014. "State-of-the-Art on Use of Insects as Animal Feed." *Animal Feed Science and Technology* 197: 1–33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

Malabo Montpellier Panel 2022. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy Report*. Kigali, Rwanda: Malabo Montpellier Panel.

Matandirotya, N.R., W.L. Filho, G. Mahed, B. Maseko, and C.V. Murandu. 2022. "Edible Insects Consumption in Africa towards Environmental Health and Sustainable Food Systems: A Bibliometric Study." *International Journal of Environmental Research and Public Health* 19 (22): 14823. http://doi.org/10.3390/ijerph192214823

Mbogori, T., K. Kimmel, M. Zhang, J. Kandiah, and Y. Wang. 2020. "Nutrition Transition and Double Burden of Malnutrition in Africa: A Case Study of Four Selected Countries with Different Social Economic Development." *AIMS Public Health* 7 (3): 425–439. http://doi.org/10.3934/publichealth.2020035

Mclachlan, M., and A. Landman. 2013. "Nutrition-Sensitive Agriculture–A South African Perspective." *Food Security* 5: 857–871. https://doi.org/10.1007/s12571-013-0309-1

Miech, P., Å. Berggren, J.E. Lindberg, T. Chhay, B. Khieu, and A. Jansson. 2016. "Growth and Survival of Reared Cambodian Field Crickets (*Teleogryllus testaceus*) Fed Weeds, Agricultural and Food Industry By-products." *Journal of Insects as Food and Feed,* 2 (4): 285–292. https://doi.org/10.3920/JIFF2016.0028

Mlambo, A., and M. Maphosa. 2022. "Mycorrhizal and Non-mycorrhizal Mushroom Cultivation-Constraints and Opportunities for Sub-Saharan Africa." *Cogent Food & Agriculture* 8 (1): 2147486. https://doi.org/10.1080/23311932.2022.2147486

Mordor Intelligence. 2024. *Aquaponics Market Size & Share Analysis - Growth Trends & Forecasts (2024 - 2029).* Hyderabad, India: Mordor Intellidence. https://www.mordorintelligence.com/industry-reports/aquaponics-market

Mpadi, N.C., and D-B.M. Bangala. 2020. "Use of the Fungus Pleurotus sajor-caju for the Delignification of a Substrate Based on Banana Flower Stalks (Musa spp.) and the Production of Edible Fungi." *International Journal of Biological and Chemical Sciences* 13 (7): 3164–3176. https://dx.doi.org/10.4314/ijbcs.v13i7.16

Munir, N., A.N.M. Ramli, N.F.S. Norsazali, and P. Bhuyar. 2023. "Valorization of Agro-industrial Waste for the Advancement of Mushrooms and Their Production Yield." *Biomass Conversion and Biorefinery*. http://doi.org/10.1007/s13399-023-04773-x

Murugu, D.K., A.N. Onyango, A.K. Ndiritu, I.M. Osuga, C. Xavier, D. Nakimbugwe, and C.M. Tanga. 2021. "From Farm to Fork: Crickets as Alternative Source of Protein, Minerals, and Vitamins." *Frontiers in Nutrition* 8: 704002. http://doi.org/10.3389/fnut.2021.704002

Musundire, R., C.J. Zvidzai, C. Chidewe, B.K. Samende, and F.A. Manditsera. 2014. "Nutrient and Anti-nutrient Composition of *Henicus whellani* (Orthoptera: Stenopelmatidae), an Edible Ground Cricket, in South-eastern Zimbabwe." *International Journal of Tropical Insect Science* 34 (4): 223–231. http://doi.org/10.1017/s1742758414000484

Niassy, S., and S. Ekesi. 2017. "Eating Insects has Long Made Sense in Africa: The World Must Catch Up." *The Conversation*, January 10. https://theconversation.com/eating-insects-has-long-made-sense-in-africa-the-world-must-catch-up-70419#:~:text=The%20dominant%20insect%20eating%20countries%20are%20the%20Democratic,Cameroon%2C%20Uganda%2C%20Zambia%2C%20Zimbabwe%2C%20Nigeria%20and%20South%20Africa

Nxasana, N., K.E. Oladimeji, G-A. Pulido-Estrada, and T.R. Apalata. 2023. "Prevalence of Micronutrient Deficiency among People Living with HIV in Selected Rural Districts of the Eastern Cape Province of South Africa." *Nutrients* 15 (13): 3017. https://doi.org/10.3390/nu15133017

Nyakeri, E.M., H.J. Ogola, M.A. Ayieko, and F.A. Amimo. 2017. "An Open System for Farming Black Soldier Fly Larvae as a Source of Proteins for Smallscale Poultry and Fish Production." *Journal of Insects as Food and Feed* 3 (1): 51–56. http://doi.org/10.3920/jiff2016.0030

Obirikorang, K.A., W. Sekey, B.A. Gyampoh, G. Ashiagbor, and W. Asante. 2021. "Aquaponics for Improved Food Security in Africa: A Review." *Frontiers in Sustainable Food Systems* 5: 705549. https://doi.org/10.3389/fsufs.2021.705549

Ohanenye, I.C., C.U. Emenike, A. Mensi, S. Medina-Godoy, J. Jin, T. Ahmed, X. Sun, and C.C. Udenigwe. 2021. "Food Fortification Technologies: Influence on Iron, Zinc and Vitamin A Bioavailability and Potential Implications on Micronutrient Deficiency in Sub-Saharan Africa." *Scientific African* 11: e00667. https://doi.org/10.1016/j.sciaf.2020.e00667

Okai, E.K.. 2021. "A Fertile New Market in African Aquaponics." *Fish Site Articles,* January 15. https://thefishsite.com/articles/a-fertile-new-market-in-african-aquaponics

Okomoda, V.T., S.A. Oladimeji, S.G. Solomon, S.O. Olufeagba, S.I. Ogah, and M. Ikhwanuddin. 2023. "Aquaponics Production System: A Review of Historical Perspective, Opportunities, and Challenges of its Adoption." *Food Science & Nutrition* 11, 3: 1157–1165. https://doi.org/10.1002/fsn3.3154

Okyere, J., I.E. Donkoh, A-A. Seidu, B.O. Ahinkorah, R.G. Aboagye, and S. Yaya. 2024. "Mother–Child Dyads of Overnutrition and Undernutrition in Sub-Saharan Africa." *Journal of Health, Population and Nutrition* 43: 1. https://doi.org/10.1186/s41043-023-00479-y

Oluwole, V. 2024. "10 African Countries That Waste the Most Food in 2024." *Business Insider Africa,* March 29. https://africa.businessinsider.com/local/lifestyle/10-african-countries-that-waste-the-most-food-in-2024/69s1wqc

Orkusz, A. 2021. "Edible Insects versus Meat—Nutritional Comparison: Knowledge of Their Composition is the Key to Good Health." *Nutrients* 13 (4): 1207. http://doi.org/10.3390/nu13041207

Pachapur, V. L., S. J. Sarma, S. K. Brar, and E. Chaabouni. 2016. "Platform Chemicals: Significance and Need." In *Platform Chemical Biorefinery*, eds. S.K. Brar, S.J. Sarma and K. Pakshirajan, 1–20. Amsterdam, Netherlands: Elsevier. https://doi.org/10.1016/B978-0-12-802980-0.00001-8

Pachón, E.R., P. Vaskan, J.K. Raman, and E. Gnansounou. 2018. "Transition of a South African Sugar Mill towards a Biorefinery. A Feasibility Assessment." *Applied Energy* 229: 1–17. https://doi.org/10.1016/j.apenergy.2018.07.104

Parker, M., S. Zobrist, K. Mansen, S. Soor, A. Laar, C. Asiedu, and H. Lutterodt. 2017. "Nutrient Analysis of Farmed Palm Weevil Larvae for the Advancement of Edible Insects in Ghana." *The FASEB Journal* 31 (S1): 639.36–639.36. https://doi.org/10.1096/fasebj.31.1_supplement.639.36

Pells, R. 2023. "How France became the Unlikely Home of the Insect-Farming Industry." *Nature Spotlight*, February 2. https://www.nature.com/articles/d41586-023-00290-z

Pneuma Food Scientifics. 2023. "Instant High-Fruit Fibre Porridge (with Mango & Pineapple)." Accessed May 13, 2024. https://pfs.ayekoomart.com/product/fibrelicious-instant-high-fruit-fibre-porridge-mangopineapple320g/

Promwee, A., K. Chinarak, W. Panpipat, A. Panya, N. Phonsatta, M. Harcet, and M. Chaijan. 2023. "Balancing the Growth Performance and Nutritional Value of Edible Farm-raised Sago Palm Weevil (*Rhynchophorus ferregineus*) Larvae by Feeding Various Plant Supplemented-Sago Palm Trunk Diets." *Foods* 12 (18): 3474. http://doi.org/10.3390/foods12183474

Robinson, B., K. Winans, A. Kendall, J. Dlott, and F. Dlott. 2018. "A Life Cycle Assessment of *Agaricus bisporus* Mushroom Production in the USA." *The International Journal of Life Cycle Assessment* 24: 456–467. http://doi.org/10.1007/s11367-018-1456-6

Salomone, R., G. Saija, G. Mondello, A. Giannetto, S. Fasulo, and D. Savastano. 2017. "Environmental Impact of Food Waste Bioconversion by insects: Application of Life Cycle Assessment to Process Using *Hermetia illucens*." *Journal of Cleaner Production* 140 (2): 890–905. http://doi.org/10.1016/j.jclepro.2016.06.154

Santoso, M.V., R.N.B. Kerr, N. Kassim, H. Martin, E. Mtinda, P. Njau, K. Mtei, J. Hoddinott, and S.L. Young. 2021. "A Nutrition-Sensitive Agroecology Intervention in Rural Tanzania Increases Children's Dietary Diversity and Household Food Security but Does Not Change Child Anthropometry: Results From a Cluster-Randomized Trial." *The Journal of Nutrition* 151 (7): 2010–2021. https://doi.org/10.1093/jn/nxab052

Schönfeldt, H.C., and N. Gibson Hall. 2012. “Dietary Protein Quality and Malnutrition in Africa.” *British Journal of Nutrition* 108 (S2): S69–S76. http://doi.org/10.1017/s0007114512002553

SciDev.net. 2022. “Africa Urged to Act Fast to Combat Obesity Surge.” *Scidev.net News,* March 15. https://www.news-medical.net/news/20220318/Urgent-action-needed-to-stem-the-rising-trend-of-obesity-in-Africa.aspx

Seifu, B.L., K.U. Mare, B.T. Legesse, and T.M. Tebeje. 2024. “Double Burden of Malnutrition and Associated Factors among Women of Reproductive Age in Sub-Saharan Africa: A Multilevel Multinomial Logistic Regression Analysis.” *BMJ Open* 14 (2): e073447. https://doi.org/10.1136/bmjopen-2023-073447

Sekabira, H., E. Nijman, L. Spath, P. Krutli, M. Schut, B. Vanlauwe, B. Wilde, K. Kintche, S. Kantengwa, A. Feyso, B. Kigangu, and J. Six. 2022. “Circular Bioeconomy in African Food Systems: What Is the Status Quo? Insights from Rwanda, DRC, and Ethiopia.” *PLoS ONE* 17 (10): e0276319. http://doi.org/10.1371/journal.pone.0276319

Shipanga, V., M. Kappas, and D. Wyss. 2024. “The Status of Research on Malnutrition among Children under 5 Years in Southern Africa: A Systematic Review.” *International Journal of Community Medicine and Public Health* 11 (1): 363–370. https://doi.org/10.18203/2394-6040.ijcmph20234151

Shumo, M., I.M. Osuga, F.M. Khamis, C.M. Tanga, K.K.M. Fiaboe, S. Subramanian, S. Ekesi, A. Van Huis, and C. Borgemeister. 2019. “The Nutritive Value of Black Soldier Fly Larvae Reared on Common Organic Waste Streams in Kenya.” *Scientific Reports* 9: 10110. http://doi.org/10.1038/s41598-019-46603-z

Slagle, M.L., and G. Davidowitz. 2022. “Substrate Composition Effect on Growth of *Cotinis mutabilis* (Scarabaeidae) Larvae: A Case for Detritivore Scarabs in the Insect Agriculture Industry.” *Journal of Insects as Food and Feed,* 8 (8): 937–949. https://doi.org/10.3920/JIFF2021.0056

Sobhana, A. 2019. “Evaluation of Cashew Varieties for RTS Beverage and Jam.” *Indian Journal of Horticulture* 76 (1): 155–161. https://doi.org/10.5958/0974-0112.2019.00022.7

Sobhana, A., J. Mathew, C, Raghavan, and A. Appukutan. 2015. “Development of Value Added Products from Cashew Apple Powder.” *International Journal of Tropical Agriculture* 33 (2): 1635–1639.

Suckling, J., A. Druckman, C.D. Moore, and D. Driscoll. 2020. “The Environmental Impact of Rearing Crickets for Live Pet Food in the UK, and Implications of a Transition to a Hybrid Business Model Combining Production for Live Pet Food with Production for Human Consumption.” *The International Journal of Life Cycle Assessment* 25: 1693–1709. http://doi.org/10.1007/s11367-020-01778-w

Tanga, C.M., J.P. Egonyu, D. Beesigamukama, S. Niassy, K. Emily, H.J. Magara, E.R. Omuse, S. Subramanian, and S. Ekesi. 2021. “Edible Insect Farming as an Emerging and Profitable Enterprise in East Africa.” *Current Opinion in Insect Science* 48: 64–71. http://doi.org/10.1016/j.cois.2021.09.007

Theuri, G., and L-J. Wachira. 2022. “Vitamin D3 Deficiency: The Missing Component in the Physical Activity and Lifelong Health of Children and Adolescents in Sub-Sahara Africa?” In *Sport and Fitness in Children and Adolescents,* ed. L-J. Wachira, 162–249. Rijeka, Croatia: IntechOpen. http://doi.org/10.5772/intechopen.105470

UNEP (United Nations Environment Programme). 2024. *Food Waste Index Report 2024. Think Eat Save: Tracking Progress to Halve Global Food Waste*. Nairobi, Kenya: UNEP.

Us, H., J.B. Sembiring, and M.E. Safitri. 2024. “Factors Associated with Undernutrition in Children in Tanjung Raya Village, Teluk Dalam District Simeulue District.” *Journal of Midwifery and Nursing* 6 (2): 514–521.

Usubharatana, P. 2016. “Life Cycle Assessment of the Straw Mushroom Production.” *Applied Ecology and Environmental Research* 14 (1): 189–200. http://doi.org/10.15666/aeer/1401_189200

Valverde, M.E., T. Hernandez-Perez, and O. Paredes-Lopez. 2015. “Edible Mushrooms: Improving Human Health and Promoting Quality Life.” *International Journal of Microbiology* 2015: 376387. http://doi.org/10.1155/2015/376387

Vetter, J. 2019. “Biological Values of Cultivated Mushrooms — A Review.” *Acta Alimentaria* 48 (2): 229–240. http://doi.org/10.1556/066.2019.48.2.11

Vinci, G., S.A. Prencipe, L. Pucinischi, F. Perrotta, and M. Ruggeri. 2023. “Sustainability Assessment of Waste and Wastewater Recovery for Edible Mushroom Production through an Integrated Nexus. A Case Study in Lazio.” *Science of Total Environment* 903: 166044. http://doi.org/10.1016/j.scitotenv.2023.166044

Virgin, I., R. Diaz-Chavez, E.J. Morris, T. Haileselassie, K. Tesfaye, S. De Cliff, K. Njau, E. Munganyinka, F. Muyambi, and M.O. Otim. 2022. *The State of the Bioeconomy in Eastern Africa: 2022.* Stockholm: Stockholm Environment Institute (SEI), The East African Science and Technology Commission (EASTECO), and Bioinnovate Africa. https://www.sei.org/wp-content/uploads/2022/07/the-state-of-the-bioeconomy-in-eastern-africa-2022.pdf

Wade, M., and J. Hoelle. 2020. "A Review of Edible Insect Industrialization: Scales of Production and Implications for Sustainability." *Environmental Research Letters* 15: 123013. http://doi.org/10.1088/1748-9326/aba1c1

WHO Africa. 2022. "Obesity Rising in Africa, Who Analysis Finds." *WHO Africa News,* March 2. https://www.afro.who.int/news/obesity-rising-africa-who-analysis-finds

Willett, W., J. Rockström, B. Loken, M. Springmann, T. Lang, S. Vermeulen, T. Garnett, et al. 2019. "Food in the Anthropocene: The EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems." *Lancet* 393 (10170): 447–492. http://doi.org/10.1016/S0140-6736(18)31788-4

World Health Organization – Global Health Observatory. 2024. "Share of Adults Who Are Overweight (Age-Standardized) - Sex: Both Sexes - Age Group: 18+ Years." Accessed April 13, 2024. https://ourworldindata.org/grapher/share-of-adults-who-are-overweight?time=latest&region=Africa&country=

Wu, G. 2016. "Dietary Protein Intake and Human Health." *Food & Function* 7 (3): 1251–1265. http://doi.org/10.1039/c5fo01530h

Yehia, R.S. 2012. "Nutritional Value and Biomass Yield of the Edible Mushroom *Pleurotus ostreatus* Cultivated on Different Wastes in Egypt." *Innovative Romanian Food Biotechnology* 11: 9–14.

Zhang, X., H. Tang, G. Chen, L. Qiao, J. Li, B. Liu, Z. Liu, M. Li, and X. Liu. 2019. "Growth Performance and Nutritional Profile of Mealworms Reared on Corn Stover, Soybean Meal, and Distillers' Grains." *European Food Research and Technology* 245: 2631–2640. http://doi.org/10.1007/s00217-019-03336-7

Zulkifli, N., A.Y. Seok-Kian, L.L. Seng, S. Mustafa, Y.S. Kim, and R. Shapawi. 2022. "Nutritional Value of Black Soldier Fly (*Hermetia illucens*) Larvae Processed by Different Methods." *PLoS ONE* 17: e0263924. http://doi.org/10.1371/journal.pone.0263924

Chapter 9

APEC (Asia-Pacific Economic Cooperation). 2022. "Bangkok Goals on Bio-Circular-Green (BCG) Economy." Accessed May 10, 2024. https://www.apec.org/meeting-papers/leaders-declarations/2022/2022-leaders-declaration/bangkok-goals-on-bio-circular-green-(bcg)-economy

Archer, S.R., E.M. Andersen, K.I. Predick, S. Schwinning, R.J. Steidl, and S.R. Woods. 2017. "Woody Plant Encroachment: Causes and Consequences." In *Rangeland Systems,* eds. D. Briske, 25–84. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-46709-2_2

Archer, M-A., D. Kumadoh, G.N Yeboah, M.O. Kyene, E.K. Kumatia, S. Antwi, and A.A. Appiah. 2020. "Formulation and Evaluation of Capsules Containing Extracts of *Cassia sieberiana* for Improved Therapeutic Outcome." *Scientific African* 10: e00609. https://doi.org/10.1016/j.sciaf.2020.e00609

Asare, B.E. 2015. "Developments Made in Herbal Medicine Practice in Ghana." *Modern Ghana*, January 25. https://www.modernghana.com/news/594410/developments-made-in-herbal-medicine-practice-in-ghana.html.

ASEAN Cassava Center. 2024. "FAO-BIOTEC: Advancing PPA BE2 in the ASEAN Region, Building on the Experiences from Thailand | Asean Cassava." Last updated March 24. https://sustainablecassava.org/projects/FAO2024/

Aung, M.T., H. Nguyen, and B. Denduang.2020. "Power and Influence in the Development of Thailand's Bioeconomy." SEI Discussion Brief. Stockholm Environment Institute (SEI), Stockholm, Sweden. https://www.sei.org/publications/power-influence-thailands-bioeconomy/

Aung, M.T. 2021. *Bioeconomy In Thailand: At a Glance*. Stockholm: SEI. https://www.sei.org/wp-content/uploads/2021/04/sei-db-bioeconomy-thailand-aung-apr-2021-updated.pdf

Babendreier, D., L.K. Agboyi, P. Beseh, M. Osae, J. Nboyine, S.E.K. Ofori, J.O. Frimpong, V.A. Clottey, and M. Kenis. 2020. "Efficacy of Alternative, Environmentally Friendly Plant Protection Measures for Control of Fall Armyworm, *Spodoptera frugiperda*, in Maize." *Insects* 11 (4): 240.https://doi.org/10.3390/insects11040240

Bio Hub Asia. 2024. "Who We Are." Accessed August 5, 2024. https://biohubasia.com/who-we-are/

BIOTEC. 2024. "BIOTEC Overview." Accessed August 5, 2024. https://www.biotec.or.th/home/en/overview-en/?lang=en

Birch, C., L. Harper-Simmonds, P. Lindeque, and A. Middleton. 2017. *Namibia Case Study: Bush Control Generates Economic and Environmental Benefits*. Policy Brief. Bonn, Germany: The Economics of Land Degradation (ELD) Initiative. https://www.eld-initiative.org/fileadmin/pdf/ELD-CS_namibia_04_web_300dpi.pdf

Brazil, Acts of the Executive Branch. 2024. *National Bioeconomy Strategy*. Decree No. 12.044. Brasilia, Brazil: Official Gazette of the Union. https://www.in.gov.br/en/web/dou/-/decreto-n-12.044-de-5-de-junho-de-2024-563746407

Brazil, Ministry of Science, Technology, and Innovation. 2016. *Estratégia Nacional de Ciência, Tecnologia e Inovação2016–2022*. Brasília, Brazil: Ministry of Science, Technology, and Innovation. http://www.finep.gov.br/images/a-finep/Politica/16_03_2018_Estrategia_Nacional_de_Ciencia_Tecnologia_e_Inovacao_2016_2022.pdf

Brazil, Ministry of Science, Technology, and Innovation. 2018. *Plano de Ação em Ciência, Tecnologia e Inovação em Bioeconomia*. Brasília, Brazil: Ministry of Science, Technology, and Innovation. https://antigo.mctic.gov.br/mctic/opencms/ciencia/SEPED/Publicacoes/ENCTI/PlanosDeAcao.html

Brazil, State of Pará. 2022. "PlanBio Pará." Accessed August 5, 2024. https://www.semas.pa.gov.br/wp-content/uploads/2022/12/STATE-OF-PAR%C3%81-BIOECONOMY-PLAN-vs.INGLES.pdf

Busitema University. 2022. "Call for Applications Round 1 | Busitema University Directorate of Graduate Studies, Research, & Innovations." Accessed 15 July 2024. https://dgsri.busitema.ac.ug/news/research-and-innovation-application

CRIG (Cocoa Research Institute of Ghana). n.d. "Production and Utilisation of Coca, Cashew and Shea By-Products in Ghana." Accessed 15 July 2024. http://www.crig.org.gh/assets/COCOA,%20CASHEW%20AND%20SHEA.pdf

CREEC (Center for Research in Energy and Energy Conservation). 2024. "About Us." Accessed 15 July 2024.. https://www.creec.or.ug/about/

da Silva Pinto, R.L., A.C. Vieira, A. Scarpetta, F.S. Marques, R.M.M. Jorge, A. Bail, L.M.M. Jorge, M.L. Corazza, and L.P. Ramos. 2022b. "An Overview on the Production of Synthetic Fuels from Biogas." *Bioresource Technology Reports* 18: 101104. https://doi.org/10.1016/j.biteb.2022.101104

EASTECO (East African Science and Technology Commission). 2022. The East African Regional Bioeconomy Strategy 2021/22–2030/31. Kigali, Rwanda. https://www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/2ebdbc71-a097-11ed-9ee4-dead53a91d31/current/document/EAC-Regional-East-Africa-Bioeconomy-Strategy.pdf

ECREE (ECOWAS Center for Renewable Energy and Energy Efficiency). 2015. *National Renewable Energy Action Plans (NREAPs) (Ghana) Period [2015–2020]*. Achada Santo António, Cabo Verde: ECREE. https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_PANER/Ghana_National_Renewable_Energy_Action_Plans.pdf.

EEAS (European External Action Service). 2024a. "EU provides Uganda EUR 40M to Tackle Deforestation and Promote Reforestation." *Delegation of the European Union to Uganda News,* April 10. https://www.eeas.europa.eu/delegations/uganda/eu-provides-uganda-eur-40m-tackle-deforestation-and-promote-reforestation_en?s=127

EEAS. 2024b. "EU Provides Uganda EUR 152m to Empower Women and Girls, and Protect Forests." *Delegation of the European Union to Uganda News, March* 31. https://www.eeas.europa.eu/delegations/uganda/eu-provides-uganda-eur-152m-empower-women-and-girls-and-protect-forests_en?s=127

EMBRAPA (Brazilian Agricultural Research Corporation). 2024. "About EMBRAPA." Accessed August 5, 2024. https://www.embrapa.br/en/sobre-a-embrapa

FAO (Food and Agriculture Organization of the United Nations). 2020. *Views, Experiences and Best Practices as an Example of Possible Options for the National Implementation of Article 9 of the International Treaty*. Rome: FAO. https://www.fao.org/plant-treaty/areas-of-work/farmers-rights/inventory-on-frs/news-detail/en/c/809354/#:~:text=In%202019%2C%20the%20Ministry%20of,enterprises%2C%20and%20the%20business%20sector

FAO. 2021. *Sawlog Production Grant Scheme, Phase III Newsletter*. Issue No. 9. Kampala, Uganda: FAO. https://openknowledge.fao.org/server/api/core/bitstreams/6e38a19b-d51a-4a62-aaf1-055eda922d33/content

FAO. 2022. "Introducing Bioeconomy for Sustainable Food and Agriculture." *FAO News.* Accessed August 15, 2024. https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/resources/news/details/es/c/1480952/

FAO. 2023a. *Bioeconomy for Sustainable Food and Agriculture*. Rome: FAO. https://www.fao.org/3/cc6905en/cc6905en.pdf

FAO. 2023b. "Role of Bioeconomy in Achieving Sustainable Development Goals Outlined at Asia–Pacific Forum." *FAO News*. Accessed August 7, 2024. https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/resources/news/details/en/c/1631017/

FAO. 2024a. "FAO Organizes First High-Level Event on Advancing Bioeconomy for Sustainable Food and Agriculture in Southeast Asia." *FAO Regional Office for Asia and the Pacific News,* May 20. https://www.fao.org/asiapacific/news/news-detail/fao-organizes-first-high-level-event-on-advancing-bioeconomy-for-sustainable-food-and-agriculture-in-southeast-asia/en

FAO. 2024b. "Workbook: Bioeconomy Strategies Dashboard." Accessed August 15, 2024. https://tableau.apps.fao.org/views/Bioeconomystrategiesdashboard/Nationalbioeconomystrategiescountryprofiles?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

FGV (Fundação Getulio Vargas). 2021. "FGV launches Bioeconomy Knowledge and Innovation Observatory." *FGV News,* November 4. https://portal.fgv.br/en/news/fgv-launches-bioeconomy-knowledge-and-innovation-observatory

FGV. 2022. *Bioeconomy Monthly Newsletter*. Edition 6. Rio de Janeiro: FGV. https://agro.fgv.br/sites/default/files/2023-03/nl_6_2022_en%20%281%29.pdf

Ghana, Ministry of Food and Agriculture. 2022. *Statistics, Research & Information*. Accra. https://mofa.gov.gh/site/directorates/line-directorate/statistics-research-information

G20. 2024a. "By 2030, We Will Announce to the World: Zero Deforestation in Brasil, States President Lula." *G20 Brasil News,* April 12. https://www.g20.org/en/news/by-2030-we-will-announce-to-the-world-zero-deforestation-in-brasil-states-president-lula

G20. 2024b. "Initiative on Bioeconomy." Accessed July 15, 2024. https://www.g20.org/en/tracks/sherpa-track/bioeconomy-initiative

Ghana, Ministry of Health. 2021. *Agriculture in Ghana (Facts & Figures).* Accra.

GCIC (Government Citizen Interaction Centre). 2022. *Science, Technology, and Innovation Secretariat Funding Opportunity Announcement*. Kampala, Uganda: GCIC. https://www.gcic.go.ug/innovationgrant/

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH). 2019. *Improving Livelihoods: Stories from GIZ Projects in Namibia*. Bonn and Eschborn, Germany: GIZ. https://www.giz.de/de/downloads/giz2022-en-namibia-employment-impact.pdf

IBA (Brazilian Tree Industry). (2021. *Brazilian Tree Industry Annual Report 2021.* Brasília, Brazil: IBA. https://iba.org/datafiles/publicacoes/relatorios/relatorioiba2021-compactado.pdf

IEA (International Energy Agency). 2023. *Uganda Energy Transition Plan*. Paris: IEA. https://iea.blob.core.windows.net/assets/00e4c677-4009-4d56-9a6b-accf14ca8456/UgandaEnergyTransitionPlan.pdf

IEA. 2024. "Uganda." Accessed June 15, 2024. https://www.iea.org/countries/uganda/energy-mix

IACGB (International Advisory Council on Global Bioeconomy). 2020. *Global Bioeconomy Policy Report (IV): A Decade of Bioeconomy Policy Development Around the World*. Berlin: IACGB. https://gbs2020.net/wp-content/uploads/2021/04/GBS-2020_Global-Bioeconomy-Policy-Report_IV_web-2.pdf

IACGB. 2024. *Bioeconomy Globalization: Recent Trends and Drivers of National Programs and Policies.* Berlin: IACGB. https://www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/52440fb0-f35d-11ee-9ed1-dead53a91d31/current/document/Global_Bioeconomy_-_April_2024_IACGB.pdf

Johnson, F.X., N. Canales, M. Fielding, G. Gladkykh, M.T. Aung, R. Bailis, R., M. Ogeya, and O. Olsson. 2022. "A Comparative Analysis of Bioeconomy Visions and Pathways Based on Stakeholder Dialogues in Colombia, Rwanda, Sweden, and Thailand." *Journal of Environmental Policy & Planning* 24 (6): 680-700. https://doi.org/10.1080/1523908X.2022.2037412

Kazibwe, K. 2024. "EU Gives Uganda Shs167bn to Tackle Deforestation." *The Nile Post*, April 10. https://nilepost.co.ug/news/195050/eu-gives-uganda-shs167bn--to-tackle-deforestation

Khaemba, W. 2018. *A Baseline Assessment of Public-Private Partnerships in Research and Scientific Cooperation in Uganda*. Nairobi: African Centre for Technology Studies (ACTS). https://www.acts-net.org/images/SGCI/Baseline-Reports/Baseline-Report-Uganda.pdf

Kumadoh, D., M-A. Archer, G.N. Yeboah, M.O. Kyene, M. Boakye-Yiadom, O. Adi-Dako, C. Osei-Asare, E. Adase, A.A. Appiah, and S.O. Mintah. 2021. "A Review on Anti-peptic Ulcer Activities of Medicinal Plants Used in the Formulation of *Enterica, Dyspepsia* and *NPK 500* Capsules." *Heliyon* 7 (12): e08465. https://doi.org/10.1016/j.heliyon.2021.e08465

Kumagai, S. 2022. *BCG (Bio-Circular-Green) Economy in Thailand*. Pacific Business and Industries, vol. XXII, no. 84. Tokyo: Sakura Institute of Research (SIR). https://www.jri.co.jp/en/MediaLibrary/file/english/periodical/rim/2022/84.pdf

Kumatia, E.K., F. Ofosu-Koranteng, A.A. Appiah, and K.B. Barimah. 2021. "Standardization and Quality Control of the Herbal Medicine Mist Nibima, Employed to Treat Malaria and COVID-19, Using Physicochemical and Organoleptic Parameters and Quantification of Chemical Markers via UHPLC-MS/MS." *International Journal of Analytical Chemistry.* 2021 (1): 6390481. https://doi.org/10.1155/2021/6390481

Lakapunrat, N., and G.B. Thapa. 2017. "Policies, Socioeconomic, Institutional and Biophysical Factors Influencing the Change from Rice to Sugarcane in Nong Bua Lamphu Province, Thailand." *Environmental Management* 59 (6): 924–938.

Lira University. 2024. "Lira University Research and Innovations Fund Request for Applications." Accessed June 7, 2024. https://lirauni.ac.ug/research-and-innovations-fund/

Makerere University. 2023. *Makerere University Research and Innovations Fund*. Kampala, Uganda: Mekerere University. https://rif.mak.ac.ug/wp-content/uploads/2023/09/MakRIF5-Grant-Guidelines-RFA-1.pdf

Malabo Montpellier Panel. 2022. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy*. Kigali, Rwanda: AKADEMIYA2063. https:/www.mamopanel.org/resources/bioeconomy/reports-and-briefings/natures-solutions-policy-innovations-and-opportuni/

Malabo Montpellier Panel. 2024. *Youth Ahead: Policy Innovations to Create Opportunities for Young People in Africa's Agrifood Systems*. Kigali, Rwanda: AKADEMIYA2063. https://www.mamopanel.org/media/uploads/files/YOUTH_AHEAD_Policy_Innovations_to_Create_Opportunities_for_Young_People_in_Africas_Agrifood_Systems_9wOvH4k.pdf

Manivong, P., and E. Bourgois. 2017. *Thai Sugarcane Sector and Sustainability*. White Paper. Bangkok: FairAgora Asia. https://www.bonsucro.com/wp-content/uploads/2017/08/Thai-White-Paper-FINAL-LowRes.docx.pdf

Maximo, Y.I.; M. Hassegawa, P.J. Verkerk, and A.L. Missio. 2022. "Forest Bioeconomy in Brazil: Potential Innovative Products from the Forest Sector." *Land* 11 (8): 1297. https://doi.org/10.3390/land11081297

Mensah, A., and C. Gordon. 2020. "Strategic Partnerships Between Universities and Non-academic Institutions for Sustainability and Innovation: Insights from the University of Ghana." In *Sustainability Challenges in Sub-Saharan Africa I*, eds. A. Gasparatos, A. Ahmed, M. Naidoo, A. Kranja, L. Fukushi, O. Saito, and K. Takeuchi, 245–278. Singapore: Springer. https://doi.org/10.1007/978-981-15-4458-3_8

Mufumba, I. (2022). *Caution the keyword as govt takes on biofuels*. https://www.monitor.co.ug/uganda/news/national/caution-the-keyword-as-govt-takes-on-biofuels-3837370

Muthui, V.A., and C.B. Nuwakora. 2019. *Terminal Evaluation Report: Addressing Barriers to Adoption of Improved Charcoal Production Technologies and Sustainable Land Practices through an Integrated Approach*. Kampala, Uganda: Ministry of Energy and Mineral Development.

NaCRRI (National Crops Resources Research Institute). 2024. "NaCRRI." National Agricultural Research Organisation. Accessed August 30, 2024.

Ninsiima, R. 2020. "Gov't Steps in to Support Research and Innovation at Makerere University." *Thrive Latest,* July 18. https://www.thrive.or.ug/blog/govt-steps-in-to-support-research-and-innovation-at-makerere-university/

OECD (Organisation for Economic Co-operation and Development). 2021. *Guidance For a Biorefining Roadmap for Thailand*. OECD Science, Technology and Industry Policy Papers. Paris: OECD. https://www.oecd-ilibrary.org/docserver/60a2b229-en.pdf?expires=1712237328&id=id&accname=guest&checksum=8860E33CFDA57823D4E9028C5A9EB61F

Ogwu, M.C., C.S. Izah, A.A.C. Alves, and S.C. Babu. 2024. *Sustainable Cassava: Strategies from Production through Waste Management*. London: Academic Press. https://shop.elsevier.com/books/sustainable-cassava/chidozie-ogwu/978-0-443-21747-0

da Silva Pinto, R.L., A.C. Vieira, A. Scarpetta, F.S. Marques, R.M.M. Jorge, A. Bail, L.M.M. Jorge, M.L. Corazza, and L.P. Ramos. 2022b. "An Overview on the Production of Synthetic Fuels from Biogas." *Bioresource Technology Reports* 18: 101104. https://doi.org/10.1016/j.biteb.2022.101104

PIBID (Presidential Initiative On Banana Industrial Development). 2024. "About PIBID." Accessed July 13, 2024. https://www.pibid.org/

Poku, A-G., R. Birner, and S. Gupta. 2018. "Making Contract Farming Arrangements Work in Africa's Bioeconomy: Evidence from Cassava Outgrower Schemes in Ghana." *Sustainability* 10 (5); 1604. https://doi.org/10.3390/su10051604

Republic of Namibia, Ministry of Higher Education, Training and Innovation and National Commission on Research, Science, and Technology. 2024. *The Namibian Sustainable Bioeconomy Strategy 2024 – 2029*. Windhoek, Namibia: Ministry of Higher Education, Training and Innovation and National Commission on Research, Science, and Technology.

Rinn, R., M. Jankovský, P. Palátová, S.P. García-Jácome, A. Sharp, P. Wangpakapattanawong, N. Lovrić, et al. 2024. "Bioeconomy in Countries of the Mekong Region: Stakeholder Understanding and Perceptions in Thailand, Vietnam, and Laos." *Forest Policy and Economics* 162: 103190. https://doi.org/10.1016/j.forpol.2024.103190

SGCI (Science Granting Councils Initiative). 2024. "About Us." Accessed July 15, 2024. https://sgciafrica.org/about-us/

Scheiterle, L., and R. Birner. 2020. "Considerations on the Role of Institutions and Networks in the Bioeconomy: Three Case Studies from Ghana and Brazil." Working Paper No. 196. ZEF Center for Development Research, Bonn, Germany. https://www.researchgate.net/publication/344218911_Considerations_on_the_role_of_institutions_and_networks_in_the_bioeconomy_three_case_studies_from_Ghana_and_Brazil.

Sequa. 2022. *Marula Oil from Namibia*. Bonn, Germany. https://www.sequa.de/fileadmin/user_upload/03_Projekttypen/Importfoerderung/230103_GIZ_MULTI904_SuS_MarulaOil_Namibia_final.pdf

Siyasa, J. 2023. "UCU Proves Insect Value in Nutrition and Alleviating Food Waste." *Uganda Christian University News,* May 17. https://ucu.ac.ug/university-proves-insect-value-in-nutrition-and-alleviating-food-waste/

Thailand, Board of Investment. 2019. *Thailand's Bio-economy*. Bangkok: Board of Investment. https://www.boi.go.th/upload/content/BOI_brochure_BioEconomy.pdf

Thailand, National Science and Technology and Development Agency. 2021. *Bio-Circular-Green Economy 2021-2027 Action Plan*. Bangkok: National Science and Technology and Development Agency. https://www.bcg.in.th/eng/wp-content/uploads/2022/07/BCG_Action_Plan_-Eng_Small.pdf

Thailand, National Science and Technology and Development Agency. 2023. Diagnostic Technology Offers Solutions for Combating Cassava Mosaic Disease. Bangkok: National Science and Technology and Development Agency. https://www.nstda.or.th/en/news/news-years-2023/diagnostic-technology-offers-solutions-for-combating-cassava-mosaic-disease.html

Thailand, Ministry of Industry. 2016. *Thai Industrial Development Strategy 4.0*. Bangkok: Ministry of Industry. https://waa.inter.nstda.or.th/stks/pub/2017/20171114-oie.pdf

Thailand, Ministry of Industry. 2018. *Thailand 4.0 The Next Revolution*. Bangkok: Ministry of Industry. https://www.industry.go.th/web-upload/1xff0d34e409a13ef56eea54c52a291126/m_magazine/12668/373/file_download/b29e16008a87c72b354efebef853a428.pdf

Thailand, Ministry of Industry. 2019. *The Achievement in Implementation of the Government Policy and Industrial Strategy Fiscal Year 2018*. Bangkok: Ministry of Industry. https://www.industry.go.th/web-upload/1xff0d34e409a13ef56eea54c52a291126/m_magazine/12668/370/file_download/11ab8f091912212902fb9b8112a18ba9.pdf

Thailand, Ministry of Natural Resources and Environment. 2015. *Master Plan for Integrated Biodiversity Management B.E. 2558 – 2564 (2015-2021)*. Bangkok: Ministry of Natural Resources and Environment. https://www.cbd.int/doc/world/th/th-nbsap-v4-en.pdf

Thailand, Ministry of Science and Technology. 2012. *Thailand National Biotechnology Framework, 2012–2021*. Bangkok: Ministry of Science and Technology. http://www.biotec.or.th/en/images/document/1.pdf

Thailand, National Science and Technology Development Agency. 2022. *BCG Action Plan 2021–2027*. Khlong Nueng. https://www.nstda.or.th/en/news-media/printed-media/bcg-action-plan-english-version.html

TotalEnergies Uganda. 2023. "Uganda Is Running Out of Trees: Partners Target To Grow 40 Million Trees This Year." *TotalEnergies Uganda News*, October 6. https://totalenergies.ug/uganda-running-out-trees-partners-target-grow-40-million-trees-year

Trede, R., and R. Patt. 2015. *Value Added End-Use Opportunities for Namibian Encroacher Bush*. Windhoek, Namibia: John Meinert Printing.

Uganda, Ministry of Agriculture, Animal Industry and Fisheries. 2019. *National Organic Agriculture Policy, 2019*. Entebbe, Uganda: Ministry of Agriculture, Animal Industry and Fisheries. https://www.agriculture.go.ug/wp-content/uploads/2020/09/National-Organic-Agriculture-Policy.pdf

Uganda, Ministry of Energy and Mineral Development. 2018a. *The Biofuels Act, 2018*. Kampala, Uganda: Ministry of Energy and Mineral Development. https://bills.parliament.ug/attachments/The%20Biofuels%20Act,%202018.pdf

Uganda, Ministry of Energy and Mineral Development. 2018b. *Uganda Biomass Energy Strategy*. Kampala, Uganda: Ministry of Energy and Mineral Development. https://data.unhcr.org/es/documents/details/64163

Uganda, Ministry of Energy and Mineral Development. 2023. *Energy Policy for Uganda, 2023*. Kampala, Uganda: Ministry of Energy and Mineral Development. https:/www.globalrightsalert.org/sites/default/files/2024-02/Energy%20Policy%20for%20Uganda%202023-14082023docx_230911_114502%20%281%29.pdf

Uganda, Ministry of Science, Technology, and Innovation. 2020. *National Bioeconomy Policy (NBP) Uganda*. Kampala, Uganda: Ministry of Science, Technology, and Innovation. https://ncri.go.ug/document/national-bioeconomy-policy/

Uganda, Ministry of Water and Environment. 2022. *Investing in Forests and Protected Areas for Climate-Smart Development (IFPA-CD)*. Kampala, Uganda: Ministry of Water and Environment. https://ugandawildlife.org/wp-content/uploads/2022/07/Project-Brief-for-Ugandas-Investing-in-Forests-and-Protected-Areas-for-Climate-Smart-Develpment-IFPA-CD-Project.pdf

Uganda, Ministry of Water and Environment. 2024. *Investing in Forests and Protected Areas for Climate-Smart Development Project*. Kampala, Uganda: Ministry of Water and Environment. https://www.mwe.go.ug/library/investing-forests-and-protected-areas-climate-smart-development-project

Uganda, National Agricultural Research Organisation. 2024a. "Anti-tick Vaccine Breakthrough." Accessed June 7, 2024. https://naro.go.ug/anti-tick-vaccine-breakthrough/

Uganda, National Agricultural Research Organisation. 2024b. "About Us." Accessed June 7, 2024. https://naro.go.ug/about-us/naro-about-us/

Uganda, National Agricultural Research Organisation. 2024c. "Technology & Innovation." Accessed June 7, 2024. https://naro.go.ug/research/technology-innovation/

Uganda, National Environment Management Authority. 2016. *National Biodiversity Strategy and Action Plan II (2015-2025)*. Kampala, Uganda: National Environment Management Authority. https://nema.go.ug/sites/all/themes/nema/docs/NBSAP%20Uganda%202015%20-%20Re-designed.pdf

Uganda, National Forestry Authority. 2024. "GIS & Mapping." Accessed June 7, 2024. https://www.nfa.go.ug/index.php/products-services/biomass-monitoring

Uganda, National Planning Authority. 2024. *Uganda Vision 2040*. Kampala, Uganda: National Planning Authority. https://www.greenpolicyplatform.org/sites/default/files/downloads/policy-database/UGANDA)%20Vision%202040.pdf

Uganda, National Planning Authority. 2017. *The Uganda Green Growth Development Strategy (2017/18 – 2030/31)*. Kampala, Uganda: National Planning Authority. https:/gggi.org/wp-content/uploads/2019/03/Uganda-Green-Growth-Development-Strategy-20171204.pdf

UIRI (Uganda Industrial Research Institute). 2023a. "Research and Development." Accessed June 7, 2024. https://www.uiri.go.ug/research_development

UIRI. 2023b. "Uganda Industrial Research Institute." Accessed June 7, 2024. https://www.uiri.go.ug/

UNCST (Uganda National Council for Science and Technology. 2023. *National Research Outlook Report*. Kampala, Uganda: UNCST. https://www.uncst.go.ug/manage/files/downloads/Status%20Report%202022-12.pdf

UNCST. 2024. "Who We Are." Accessed June 7, 2024. https://www.uncst.go.ug/details.php?option=smenu&id=1&Who%20we%20are.html

UNCTAD (UN Trade and Development). 2021. "Women in Rural Namibia Profit from Biodiversity-Friendly Trade." May 19. https://unctad.org/news/women-rural-namibia-profit-biodiversity-friendly-trade

UNEP (United Nations Environment Programme). 2015. *Green Economy Assessment Report Ghana, 2015*. Nairobi: UNEP. https://www.un-page.org/files/public/ge_ghana_assessmentreport_web.pdf.

UNDP (United Nations Development Programme). 2020. *Biodiversity Finance Plan for Thailand*. New York: UNDP. https://www.undp.org/sites/g/files/zskgke326/files/migration/th/UNDP-TH-BIOFIN-The-Biodiversity-Finance-Plan-for-Thailand.pdf

UNREEEA (Uganda National Renewable Energy & Energy Efficiency Alliance). 2024. "Uganda National Renewable Energy & Energy Efficiency Alliance." Accessed June 7, 2024. https://unreeea.org/

USAID. 2022. Namibian Marula Oil Makes it to America. September 22. https://www.usaid.gov/namibia/news/sep-22-2022-namibian-marula-oil-makes-it-america

Virchow, D., T.D. Beuchelt, A. Kuhn, and M. Denich. 2016. "Biomass-based Value Webs: A Novel Perspective for Emerging Bioeconomies in Sub-Saharan Africa." In *Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development*, eds. F. Gatzweiler and J. von Braun, 225–238. Cham, Switzerland: Springer Open. https://www.zef.de/fileadmin/user_upload/tbeuchelt_download_VirchowBeucheltEtAl-2016-BiomassbasedValueWebs-NovelPerspectiveEmergingBioeconomiesInSSA.pdf

Workman, D. 2024. "Namibia's Top 10 Exports." Accessed June 30, 2024. https://www.worldstopexports.com/namibias-top-10-exports/

World Bank. 2020. "World Bank Invests $148.2 Million to Improve Uganda's Forest Management and Provide Benefits to Communities, including Refugees." *World Bank News,* April 23. https://www.worldbank.org/en/news/press-release/2020/04/23/world-bank-invests-1482-million-to-improve-ugandas-forest-management-and-provide-benefits-to-communities-including-refugees

World Bio Market Insights. 2023. "Brazil's Amazonian Bioeconomy Offers Hope for Stemming Deforestation." *World Bio Market Insights News*. Accessed July 15, 2024. https://worldbiomarketinsights.com/brazils-amazonian-bioeconomy-offers-hope-for-stemming-deforestation/

Featured Issue 1

Abro, Z., M. Kassie, T. Chrysantus, D. Beesigamukama, and G. Diiro. 2020. "Socioeconomic and Environmental Implications of Replacing Conventional Poultry Feed with Insect-Based Feed in Kenya." *Journal of Cleaner Production* 265: 121871.

Featured Issue 1 References *continued*

Abro, Z., M. Kassie, B. Muriithi, M. Okal, D, Masiga, G. Wanda, A. Samuel, et al. 2021. "The Potential Economic Benefits of Controlling Trypanosomiasis Using Waterbuck Repellent Blend in Sub-Saharan Africa." PLoS ONE 16 (7): e0254558.

AfDB (African Development Bank). 2024. *African Economic Outlook 2024*. Abidjan, Cote d'Ivoire.

AGRA (Alliance for a Green Revolution in Africa). 2022. *Africa Agriculture Status Report 2023: Empowering Africa's Food Systems for the Future (Issue 11)*. Nairobi, Kenya.

Ala-Kokko, K., L.L. Nalley, A.M. Shew, J.B. Tack, P. Chaminuka, M.D. Matlock, and M. D'Haese. 2021. "Economic and Ecosystem Impacts of GM Maize in South Africa." *Global Food Security* 29: 100544. https://doi.org/10.1016/j.gfs.2021.100544

AUC (African Union Commission). 2013. *African Union Agenda 2063*. Addis Ababa, Ethiopia.

Beesigamukama, D., S. Subramanian, and C.M. Tanga. 2022a. "Nutrient Quality and Maturity Status of Frass Fertilizer from Nine Edible Insects." *Scientific Reports* 12 (1): 7182. https://doi.org/10.1038/s41598-022-11336-z

Beesigamukama, D., B. Mochoge, N. Korir, M. Kassie, B. Muriithi, M. Kidoido, H. Kirscht, et al. 2022b. "Economic and Ecological Values of Frass Fertiliser from Black Soldier Fly Agro-industrial Waste Processing." *Journal of Insects as Food and Feed* 8 (3): 245-254. https://doi.org/10.3920/JIFF2021.0013.

CBD (United Nations Convention on Biological Diversity). 1992. *Convention on Biological Diversity: Text and Annex*. Secretariat of the Convention of Biological Diversity. Montreal, Canada.

CBD. 2010. Nagoya Protocol on *Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity: Text and Annex*. Secretariat of the Convention on Biological Diversity. Montreal, Canada.

Chia, S.Y., J. Macharia, G.M. Diiro, M. Kassie, S. Ekesi, J.J.A. van Loon, M. Dicke, and C.M. Tanga. 2020. "Smallholder Farmers' Knowledge and Willingness to Pay for Insect-Based Feeds in Kenya." PLoS ONE 15 (3): e0230552.

EAC (East African Community). 2022. *The East African Regional Bioeconomy Strategy 2021/22 - 2031/32*. Arusha, Tanzania: EAC.

IACGB (International Advisory Council on Global Bioeconomy). 2024. *Bioeconomy Globalisation: Recent Trends and Drivers of the National Programs and Policies*. Germany.

Lang, C. 2022. "Bioeconomy - From the Cologne Paper to Concepts for a Global Strategy." *EFB Bioeconomy Journal* 2: 100038. https://doi.org/10.1016/j.bioeco.2022.100038

Malabo Montpellier Panel. 2022. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy*. Kigali, Rwanda: AKADEMYIA 2063.

Koch, M. 2004. "The Case for GMOs in the Developing World—How African Farmers are Benefiting from Biotechnology." In *New Directions for a Diverse Planet: Proceedings of the 4th International Crop Science Congress*, vol. 26.

Ogwang, P.E., S.S. Twinomujuni, C.U. Tolo, and F. Wasswa. 2024. "Preclinical Immunomodulatory Activity of COVIDEX® Herbal Product Developed for Supportive Treatment of COVID-19 in Uganda." *African Journal of Pharmacy and Pharmacology* 18 (6): 96–102. https://doi.org/10.5897/AJPP2023.5371

Patermann, C., and A. Aguilar. 2018. "The Origins of the Bioeconomy in the European Union." *New Biotechnology* 40 (Part A): 20–24. https://doi.org/10.1016/j.nbt.2017.04.002

Pasa, V.M.D., C.A. Scaldadaferri, and H. dos Santos Oliveira. 2022. "Chapter 4 - Main Feedstock for Sustainable Alternative Fuels for Aviation." In *Sustainable Alternatives for Aviation Fuels*, eds. A. Yousuf, and C. Gonzalez-Fernandez, 69–102. https://doi.org/10.1016/B978-0-323-85715-4.00005-7

von Braun, J. 2018. "Bioeconomy – The Global Trend and Its Implications for Sustainability and Food Security." *Global Food Security* 19: 81–83. https://doi.org/10.1016/j.gfs.2018.10.003

Weisenfeld, U., A. Hauerwaas, O. Elshiewy, P. Halder, J. Wesseler, K. Cingiz, and I. Broer. 2023. "Beyond Plastic – Consumers Prefer Food Packaging Derived from Genetically Modified Plants." *Research Policy* 52 (10): 104883. https://doi.org/10.1016/j.respol.2023.104883

WBCSD (World Business Council on Sustainable Development). 2020. *Circular Bioeconomy: The Business Opportunity Contributing to a Sustainable World*. Geneva, Switzerland.

World Bank. 2020 *The African Continental Free Trade Area: Economic and Distributional Effects*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1559-1

World Bank. World Bank Databank. Accessed July 25, 2023. https://databank.worldbank.org/

Xinhua. 2021. "Home-based Care Solutions for COVID-19 Prevention in Zambia on the Rise. January 20. http://www.xinhuanet.com/english/2021-01/20/c_139684042.htm

Chapter 10

Adeniyi, D. 2023a. "Adaptation Finance to Local Food Systems in Kenya." Discussion Paper No. 348. European Centre for Development Policy Management (ECDPM), Maastricht, the Netherlands. https://ecdpm.org/work/adaptation-finance-local-food-systems-kenya

Adeniyi, D. 2023b. "Enhancing European Financing for Adaptation to Cascading Climate Risks: Three Key Takeaways." *ECDPM Commentary*, October 16.https://ecdpm.org/work/enhancing-european-financing-adaptation-cascading-climate-risks-three-key-takeaways

Adeniyi, D. Forthcoming. *Local Ecosystems for Increased Public and Private Investment in Adaptation*. Maastricht, the Netherlands: ECDPM.

Adhikari, B., and L.S. Safaee Chalkasra. 2023. "Mobilizing Private Sector Investment for Climate Action: Enhancing Ambition and Scaling Up Implementation." *Journal of Sustainable Finance & Investment* 13 (2): 1110–1127. https://doi.org/10.1080/20430795.2021.1917929

Adolph, B., G. Griffiths, and X. Hou-Jones. 2023. *Analysis of the Implications of Africa's Food Systems Development on Environmental Sustainability*. London: International Institute for Environment and Development (IIED). https://wwfafrica.awsassets.panda.org/downloads/africasfoodsystems.pdf

AIO (Africa Insurance Organisation). 2023. *Africa Insurance Pulse 2023*. Douala, Cameroon: AIO. https://faberconsulting.ch/files/faber/pdf-pulse-reports/2023_AIP_e_final2_web.pdf

AfDB (African Development Bank). 2019. *Analysis of Adaptation Component of Africa's Nationally Determined Contributions (NDCs).* Abidjan, Côte d'Ivoire: AfDB. www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Analysis_of_Adaptation_Components_in_African_NDCs_2019.pdf

Ahairwe, P. E., and S. Bilal. 2023. *Mobilising (European) Development Finance for Climate Adaptation and Resilience*. CASCADES Research Paper. London: Chatham House. www.cascades.eu/wp-content/uploads/2023/09/CASCADES-Mobilising-European-Development-Finance-for-Climate-Adaptation-and-Resilience.pdf

Ahairwe, P.E., S. Bilal, A. Đuranović, and I. Monasterolo. 2022a. *Climate Risk Mispricing: Why Better Assessments Matter in Financing for Development*. CASCADES Policy Brief. London: CASCADES. www.cascades.eu/publication/climate-risk-mispricing-why-better-assessments-matter-in-financing-for-development/

Ahairwe, P.E., and S. Bilal. 2022b. *AgrInvest-Food Systems Project. Leveraging Private Finance for Sustainable Agrifood Value Chains in Burkina Faso, Ethiopia, Kenya and Niger*. Rome: Food and Agriculture Organization of the United Nations (FAO). https://openknowledge.fao.org/server/api/core/bitstreams/4b8a453b-06d0-4814-9f6c-14e2cfd5ae88/content

Allen, F., I. Otchere, and L.W. Senbet. 2011. "African Financial Systems: A Review." *Review of Development Finance* 1 (2): 79–113. https://doi.org/10.1016/j.rdf.2011.03.003

Apampa A., C. Clubb, B.E. Cosgrove, G. Gambarelli, H. Loth, R. Newman, V. Rodriguez Osuna, J. Oudelaar, and A. Tasse. 2021. "Scaling Up Critical Finance for Sustainable Food Systems through Blended Finance." CCAFS Discussion Paper. Alliance Bioversity & CIAT, Rome. https://hdl.handle.net/10568/115123

Bellali, J., L. Strauch, F. Oremo, and B. Ochieng. 2018. *Multi-Level Climate Governance in Kenya: Activating Mechanisms for Climate Action*. Berlin: Adelphi; Nairobi: Institute for Law and Environmental Governance (ILEG). https://adelphi.de/de/system/files/mediathek/bilder/Multi-level%20climate%20governance%20in%20Kenya%20-%20vled%20-%20adelphi.pdf

Chiriac, D., H. Vishnumolakala, and P. Rosane. 2023a. *Landscape of Climate Finance for Agrifood Systems*. San Francisco: Climate Policy Initiative (CPI). https://www.climatepolicyinitiative.org/publication/landscape-of-climate-finance-for-agrifood-systems/

Chiriac, D., H. Vishnumolakala, and P. Rosane. 2023b. *The Climate Finance Gap for Small-Scale Agrifood Systems: A Growing Challenge*. San Francisco: CPI. www.climatepolicyinitiative.org/publication/the-climate-finance-gap-for-small-scale-agrifood-systems/

Chiriac, D., and B. Naran. 2020. *Examining the Climate Finance Gap for Small-Scale Agriculture*. San Francisco: CPI; Rome: International Fund for Agricultural Development (IFAD). https://www.climatepolicyinitiative.org/publication/climate-finance-small-scale-agriculture/

Clark, R., J. Reed, and T. Sunderland. 2018. "Bridging Funding Gaps for Climate and Sustainable Development: Pitfalls, Progress and Potential of Private Finance." *Land Use Policy* 71: 335–346. https://doi.org/10.1016/j.landusepol.2017.12.013

Convergence 2023. *The State of Blended Finance 2023: Climate Edition*. Toronto: Convergence. www.convergence.finance/resource/state-of-blended-finance-2023/view

Convergence 2021. *The State of Blended Finance 2021*. Toronto: Convergence https://www.convergence.finance/resource/the-state-of-blended-finance-2021/view

CPI and IFAD (International Fund for Agricultural Development). 2020. *Examining the Climate Finance Gap for Small-Scale Agriculture.* San Francisco: CPI. www.ifad.org/documents/38714170/42157470/climate-finance-gap_smallscale_agr.pdf/34b2e25b-7572-b31d-6d0c-d5ea5ea8f96f?t=1605021452000

D'Alessandro, C., F. Rampa, and K. Dekeyser. 2022. *Investing in Sustainable Food Systems: A Methodology and Lessons Learned from Africa*. Maastricht, the Netherlands: ECDPM. https://ecdpm.org/work/investing-sustainable-food-systems-methodology-and-lessons-learned-africa

D'Alessandro, C., D. Adeniyi, and F. Rampa. Forthcoming. *Understanding Blended Finance Schemes for Agri-food Systems in Kenya*. Maastricht, the Netherlands: ECDPM.

ECDPM (European Centre for Development Policy and Management). 2023. *ECDPM's Recommendations for the UN Food Systems Summit +2 and Beyond*. Maastricht, the Netherlands: ECDPM. https://ecdpm.org/work/ecdpms-recommendations-un-food-systems-summit-plus-2-and-beyond

ECDPM, IFAD, and CDP (Cassa Depositi e Prestiti). 2022. "Upscaling Collaborations among Public Development Banks and Private Financiers for Food Security and Food Systems." Report of a seminar on *Public Development Banks and Private Financiers for Food Security and Food Systems,* December 19. https://ecdpm.org/application/files/4716/7532/2609/Final_Report_ECDPM-IFAD-CDP_19_December_2022_event.pdf

Eichhorn, J., D. Flores, E. Ijjasz-Vasquez, and J. Saghir. 2023. "Strategy and Planning to Redouble Climate Adaptation in Africa." *Payne Commentary Series,* October 1. https://payneinstitute.mines.edu/strategy-and-planning-to-redouble-climate-adaptation-in-africa/

FAO. 2024. *The Unjust Climate – Measuring the Impacts of Climate Change on Rural Poor, Women and Youth*. Rome: FAO. https://doi.org/10.4060/cc9680en

FAO. 2023. *Climate Change Impacts and Adaptation Options in the Agrifood System: Brief Summary of the Intergovernmental Panel on Climate Change Sixth Assessment Report*. Rome: FAO. https://openknowledge.fao.org/server/api/core/bitstreams/0e0d0aef-a8f9-40ea-9024-a79c320d0fc5/content

FAO. 2022. *Greenhouse Gas Emissions from Agrifood Systems. Global, Regional and Country Trends, 2000–2020*. FAOSTAT Analytical Brief 50. Rome: FAO. https://openknowledge.fao.org/server/api/core/bitstreams/121cc613-3d0f-431c-b083-cc2031dd8826/content

FAO. 2020. *Global Forest Resources Assessment 2020: Key Findings*. Rome: FAO. https://doi.org/10.4060/ca8753en

Fazel, K., and K. Couzyn. 2021. "A New Chapter Has Opened for Commercial Funding of Sustainability Projects." *Webber Wentzel COP26 Insight Series,* October 19. https://www.webberwentzel.com/News/Pages/a-new-chapter-has-opened-for-commercial-funding-of-sustainability-projects.aspx

FOLU (Food and Land Use Coalition). 2019. *Growing Better: Ten Critical Transitions to Transform Food and Land Use*. London: FOLU. https://www.foodandlandusecoalition.org/global-report/

Galbiati, G.M., M. Yoshida, N. Benni, and M. Bernoux. 2023. *Climate-Related Development Finance to Agrifood Systems – Global and Regional Trends between 2000 and 2021*. Rome: FAO. https://doi.org/10.4060/cc9010en

Garschagen, M., and Doshi, D. (2022). "Does Funds-Based Adaptation Finance Reach the Most Vulnerable Countries?" *Global Environmental Change* 73: 102450. https://doi.org/10.1016/j.gloenvcha.2021.102450

GCA (Global Centre on Adaptation) and CPI. 2023. *State and Trends in Climate Adaptation Finance 2023*. Rotterdam: GCA; San Francisco: CPI. https://gca.org/reports/state-and-trends-in-climate-adaptation-finance-2023/?_gl=1*65i7c6*_ga*MTM0Mzk2MjEyOC4xNzA4NjAwNjQx*_up*MQ

GCA. 2023. *State and Trends in Adaptation Report 2023*. Rotterdam: GCA. https://gca.org/reports/sta23/#:~:text=STA23%20delivers%20the%20most%20up,implementing%20the%20most%20critical%20adaptation

Gomez San Juan, M., S. Harnett, and I. Albinelli. 2022. *Sustainable and Circular Bioeconomy in the Climate Agenda: Opportunities to Transform Agrifood Systems*. Rome: FAO. https://doi.org/10.4060/cc2668en

Iacobuta, G. I., C. Brandi, A. Dzebo, and S.D. Elizalde Duron. 2022. "Aligning Climate and Sustainable Development Finance through an SDG Lens. The Role of Development Assistance in Implementing the Paris Agreement." *Global Environmental Change* 74: 102509. https://doi.org/10.1016/j.gloenvcha.2022.102509

Ibrahim, M., F. Smyth, C. Wells, and E. Ritchie. 2023. "When the Data Doesn't Tell the Full Story: Improving Gender-Responsive Climate Finance." *Development Initiatives* blog, November 29. https://devinit.org/blog/data-improving-gender-responsive-climate-finance/

IFPRI (International Food Policy Research Institute). 2022. *Global Food Policy Report: Climate Change and Food Systems.* Washington, DC: IFPRI. http://doi.org/10.2499/9780896294257

IPCC (Intergovernmental Panel on Climate Change). 2022. *Summary for Policymakers.* In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change,* eds. H-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, and B. Rama, 3–33. Cambridge, UK: Cambridge University Press. https://doi.org.10.1017/9781009325844.001

ISF Advisors. 2022. *The Current State of the Agri-SME Finance Sector*. London: Foreign, Commonwealth and Development Office (FCDO). https://isfadvisors.org/the-current-state-of-the-agri-sme-finance-sector/

ISF Advisors, Mastercard Foundation, and Rural and Agricultural Finance Learning Lab. 2019. *Pathways to Prosperity: Rural and Agricultural Finance State of the Sector Report*. Washington, DC: Mastercard Foundation. https://pathways.isfadvisors.org/about/

Jimenez-Sanchez, K. 2023. "Untapped Potential in Africa's Agricultural Insurance Market." *Reinsurance News*, June 2. https://www.reinsurancene.ws/untapped-potential-in-africas-agricultural-insurance-market

Karaki, K., and S. Bilal. 2022. *Donors, Implementing Agencies and DFI/PDB Cooperation: The Case of the Netherlands and the Dutch Fund for Climate and Development*. Brussels: European Think Tanks Group (ETTG). https://ettg.eu/wp-content/uploads/2022/10/Donors-implementing-agencies-and-DFIPDB-cooperation-The-case-of-the-Netherlands-and-the-Dutch-Fund-for-Climate-and-Development.pdf

Knaepen, H., and K. Dekeyser. 2022. "EU Climate Adaptation Diplomacy: Searching for Common Ground with Africa." Discussion Paper 346. ECDPM, Maastricht, the Netherlands. https://ecdpm.org/application/files/4516/8597/2032/EU-climate-adaptation-diplomacy-searching-common-ground-Africa-ECDPM-Discussion-Paper-346-2023.pdf

Knaepen, H. 2022. *Supporting Adaptation in African Agriculture: A Policy Shift since the EU Green Deal?* Briefing Note 148. Maastricht, the Netherlands: ECDPM. https://ecdpm.org/application/files/9516/5702/3035/Supporting-adaptation-African-agriculture-ECDPM-briefing-note-148-2022.pdf

Le Houérou, P. 2023. "Climate Funds: Time to Clean Up." Working Paper 320. Foundation for Studies and Research on International Development (FERDI), Clermont-Ferrand, France. https://ferdi.fr/dl/df-z4LdsA8Y7stAvmESarbZ1jGQ/ferdi-wp320-climate-funds-time-to-clean-up.pdf

Leoussis, J., and P. Brzezicka. 2017. *Study on Access-to-Finance Conditions for Investments in Bio-based Industries and the Blue Economy*. Luxembourg City, Luxembourg: European Investment Bank (EIB). https://www.eib.org/attachments/pj/access_to_finance_study_on_bioeconomy_en.pdf

Li, B., F. Natalucci, and P. Ananthakrishnan. 2022. "How Blended Finance Can Support Climate Transition in Emerging and Developing Economies." *IMF Blog,* November 15.https://www.imf.org/en/Blogs/Articles/2022/11/15/how-blended-finance-can-support-climate-transition-in-emerging-and-developing-economies

Malabo Montpellier Panel. 2022a. *ADAPT: Policy Innovations to Unlock Climate Finance for Resilient Food Systems in Africa*. Kigali, Rwanda: Malabo Montpellier Panel. https://www.mamopanel.org/resources/climate-finance/reports-and-briefings/full-report-adapt-policy-innovations-unlock-climat/

Malabo Montpellier Panel. 2022b. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy*. Kigali, Rwanda: Malabo Montpellier Panel. https://www.mamopanel.org/resources/bioeconomy/reports-and-briefings/natures-solutions-policy-innovations-and-opportuni/

Meattle, C., R. Padmanabhi, P. de Aragão Fernandes, A. Balm, E. Wakaba, D. Chiriac, and B. Tonkonogy. 2022. *Landscape of Climate Finance in Africa*. San Francisco: CPI. https://www.climatepolicyinitiative.org/wp-content/uploads/2022/09/Landscape-of-Climate-Finance-in-Africa.pdf

Micale, V., B. Tonkonogy, and F. Mazza. 2018. *Understanding and Increasing Finance for Climate Adaptation in Developing Countries.* San Francisco: CPI. https://climatepolicyinitiative.org/wp-content/uploads/2018/12/Understanding-and-Increasing-Finance-for-Climate-Adaptation-in-Developing-Countries-1.pdf

Mustapha, S. 2022. *Using the Right Mix of Financial Instruments to Provide and Mobilize Climate Finance.* Part of the Financing Climate Action: iGST Discussion Series. San Francisco: ClimateWorks Foundation. https://www.climateworks.org/wp-content/uploads/2022/11/Using-the-Right-Mix-of-Financial-Instruments-to-Provide-and-Mobilize-Climate-Finance_iGSTFinance_Nov2022.pdf

OECD (Organisation for Economic Co-operation and Development). 2023. "Challenges in Financing Adaptation in Developing Countries." In *Scaling Up Adaptation Finance in Developing Countries: Challenges and Opportunities for International Providers,* 44–57. Paris: OECD Publishing. https://doi.org/10.1787/c19c39cd-en

Perera, O., C. Smaller, K. El Harty, and L. Lefebvre. 2023. *Unleashing the Catalytic Power of Donor Financing to Achieve SDG 2*. Geneva: Shamba Centre for Food and Climate and Global Donor Platform for Rural Development. https://www.donorplatform.org/wp-content/uploads/2023/10/GDPRD_Shamba-Centre-Finance-Enquiry_Summary-Report_18-OCT-2023_draft-5-unedited.pdf

Pettinotti, L., Y. Cao, and T. Kamninga. 2021. *Gender Equality Targeting in Adaptation Finance, 2021 Snapshot.* ODI Brief. London: ODI. https://odi.cdn.ngo/media/documents/ODI_2023_Gender_equality_targeting_in_adaptation_finance.pdf

Prasad, A., E. Loukoianova, A. Xiaochen Feng, and W. Oman. 2022. *Mobilizing Private Climate Financing in Emerging Market and Developing Economies*. Staff Climate Note No. 2022/007. Washington, DC: International Monetary Fund (IMF). https://www.imf.org/en/Publications/staff-climate-notes/Issues/2022/07/26/Mobilizing-Private-Climate-Financing-in-Emerging-Market-and-Developing-Economies-520585

Qi, J., and H. Qian. 2023. "Climate Finance at a Crossroads: It Is High Time to Use the Global Solution for Global Problems." *Carbon Neutrality* 2: 31. https://doi.org/10.1007/s43979-023-00071-7

Rampa, F., K. Dekeyser, C. D'Alessandro, D. Adeniyi, and C. Farinha. 2023. *ECDPM's Recommendations for the UN Food Systems Summit +2 and Beyond.* Maastricht: ECDPM. https://ecdpm.org/work/ecdpms-recommendations-un-food-systems-summit-plus-2-and-beyond

Restle-Steinert, J., T. Hausotter, S. Rudolph, A. Cochu, and D. Tänzler. 2019. *Steering International Adaptation Finance towards the Local Level*. Adelphi Scoping P aper. Berlin: Adelphi. https://adelphi.de/system/files/mediathek/bilder/adelphi-2019_Scoping-Paper_Steering-AdaptFin-Towards-Local-Level.pdf

Rossi, L., M. Gancheva, and S. O'Brien. 2017. *Financing Climate Action: Opportunities and Challenges for Local and Regional Authorities*. Brussels: European Committee of the Regions. https://dx.doi.org/10.2863/329600

SAFIN (Smallholder and Agri-SME Finance and Investment Network) and Convergence. 2021. "Deploying Blended Finance to Mobilize Investment at Scale in Food and Agriculture." Working Paper 8. SAFIN, Rome; Convergence, Toronto. https://safinetwork.org/internal_resources/deploying-blended-finance-to-mobilize-investment-at-scale-in-food-and-agriculture/

Schalatek, L. 2022. *Gender and Climate Finance.* Washington, DC: Heinrich Böll Stiftung. https://climatefundsupdate.org/wp-content/uploads/2022/03/CFF10-Gender-and-CF_ENG-2021.pdf

Schulte, I., H. Bakhtary, S. Siantidis, F. Haupt, M. Fleckenstein, and C. O'Connor. 2020. *Enhancing NDCs for Food Systems: Recommendations for Decision-Makers.* Berlin: World Wildlife Fund (WWF). https://wwfint.awsassets.panda.org/downloads/wwf_ndc_food_final_low_res.pdf

Soanes, M., N. Rai, P. Steele, C. Shakya, and J. Macgregor. 2017. "Delivering Real Change: Getting International Climate Finance to the Local Level." IIED Working Paper. IIED, London. www.iied.org/sites/default/files/pdfs/migrate/10178IIED.pdf

RMB. "RMB Arranges First Syndicated Sustainability-Linked Loan in Africa for Mediclinic SA." RMB and Standard Bank Group. Accessed August 2024. www.rmb.co.za/deal/rmb-arranges-first-syndicated-sustainability-linked-loan-in-africa-for-mediclinic-sa

Standard Bank Group. 2023. "USD 400 Million Sustainability-Linked Facility Closed." *Standard Bank News*, December 11. www.standardbank.com/sbg/standard-bank-group/news-and-insights/whats-happening/news/standard-bank-successfully-closes-usd-400-million-sustainability-linked-syndicated-term-loan-facility

Tall, A., S. Lynagh, C.B. Vecchi, P. Bardouille, F. Montoya Pino, E. Shabahat, V. Stenek, et al. 2021. *Enabling Private Investment in Climate Adaptation & Resilience. Current Status, Barriers to Investment and Blueprint for Action*. Washington, DC: World Bank Group. https://documents1.worldbank.org/curated/en/566041614722486484/pdf/Enabling-Private-Investment-in-Climate-Adaptation-and-Resilience-Current-Status-Barriers-to-Investment-and-Blueprint-for-Action.pdf

Thornton, P., Y. Chang, A.M. Loboguerrero, and B., Campbell. 2023. "Perspective: What Might It Cost to Reconfigure Food Systems?" *Global Food Security* 36: 100669. https://doi.org/10.1016/j.gfs.2022.100669

Throp, H., A. Yang, S. Sherman, and R. Waack, R. 2023. *How Forest Bioeconomies Can Support Nature-Based Solutions*. London: Chatham House.www.chathamhouse.org/2023/03/how-forest-bioeconomies-can-support-nature-based-solutions

Tietjen, B., F. Rampa, and H. Knaepen. 2019. *Finance to Adapt: Making Climate Funding Work for Agriculture at the Local Level*. Briefing Note 111. Maastricht: ECDPM. https://ecdpm.org/work/finance-to-adapt-making-climate-funding-work-for-agriculture-at-the-local-level

UNCTAD (United Nations Conference on Trade and Development). 2019. *SDG Investment Trends Monitor*. Geneva. https://unctad.org/system/files/official-document/diaemisc2019d4_en.pdf

UNEP (United Nations Environment Programme). 2023. *Adaptation Gap Report 2023*. Nairobi. www.unep.org/resources/adaptation-gap-report-2023

UNEP (United Nations Environment Programme). 2022. *State of Finance for Nature 2021*. https://www.unep.org/resources/state-finance-nature-2022

van Pul, J., A.G. Valladares, and E. Wolfs. 2023. *Developing Blended Finance Capacity for Nature on a National Level*. The Hague, the Netherlands: Dutch Ministry of Agriculture, Nature and Food Quality. www.idfb-dialogue.org/wp-content/uploads/2023/05/Developing-blended-finance-capacity-for-nature-on-a-national-level.pdf

Wattel, C., B. Negede, S. Desczka, H. Pamuk, M. van Asseldonk, A. Castro Núñez, G. Amahnui Amenchwi, et al. 2024. *Finance for Low-Emission Food Systems – Six Financial Instruments with Country Examples*. Low-Emission Food Systems Technical Report. Montpellier, France: CGIAR. https://hdl.handle.net/10568/138857

World Bank. 2021. "Climate Explainer: What You Need to Know About Concessional Finance for Climate Action." *World Bank Group News,* September 16. https://www.worldbank.org/en/news/feature/2021/09/16/what-you-need-to-know-about-concessional-finance-for-climate-action

Chapter 11

AFREC. 2024. "Data & Statistics on Energy in Africa." https://au-afrec.org/data-statistics-energy-browser-0

AMDA (Africa Minigrid Developers Association). 2024. "African Minigrid Development Association." https://africamda.org/

AfDB (African Development Bank). 2017. "Sustainable Energy Fund Africa." https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa

Allen, M., D. Frame, C. Huntingford, C.D. JUones, J.A. Lowe, M. Meinhausen, and N. Meinhausen. 2009. "Warming Caused by Cumulative Carbon Emissions towards the Trillionth Tonne." *Nature* 458: 1163–1166.

Evans, S. 2021. "Analysis: Which Countries are Historically Responsible for Climate Change?" *Carbon Brief*, May 10. https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change/

Faizel, I. 2021. *The African Continental Free Trade Area (AfCFTA) and Developmental Regionalism: A Handbook*. Pretoria, South Africa: Trade & Industrial Policy Strategies (TIPS).

IEA (International Energy Agency). 2022. *Africa Energy Outlook 2022*. Paris, France: IEA.

IEA, IRENA (International Renewable Energy Agency), UNSD (United Nations Statistics Division), World Bank, and WHO (World Health Organization). 2023. *Tracking SDG 7: The Energy Progress Report*. Washington, DC: World Bank.

IRENA. 2021. *Renewable Power Generation Costs in 2020*. Abu Dhabi, UAE: IRENA.

IRENA. 2022. *Off-grid Renewable Energy Statistics 2022*. Abu Dhabi: IRENA.

Khennas, S., S. Chitou, F. Kemausour, and E. Ramde. 2024. *ECOWAS Energy Outlook*. Abuja, Nigeria: ECOWAS Directorate of Energy and Mines.

Runde, D.F., C.M. Savoy, and J. Staguhn. 2021. *Supporting Small and Medium Enterprises in Sub-Saharan Africa through Blended Finance.* CSIS Brief. Washington, DC: Center for Strategic International Studies (CSIS). https://www.csis.org/analysis/supporting-small-and-medium-enterprises-sub-saharan-africa-through-blended-finance

SEforALL (Sustainable Energy for All). 2024. *State of the Global Mini Grids Market Report 2024*. Vienna: SEforALL.

UNCTAD (United Nations Conference on Trade and Development). 2023. *Economic Development in Africa Report 2023: The Potential of Africa to Capture Technology-Intensive Global Supply Chains*. New York: UNCTAD.

UNFCCC (United Nations Framework Convention on Climate Change). 2015. *The Paris Agreement to the United Nations Framework Convention on Climate Change*. Bonn, Germany: UNFCCC.

Way, R., C.I. Matthew, P. Mealy, and J.D. Farmer. 2022. "Empirically Grounded Technology Forecasts and the Energy Transition." *Joule* 6 (9): 2057–2082.

World Bank. 2020. *The African Continental Free Trade Area: Economic and Distributional Effects.* Washington, DC: World Bank.

World Bank and ESMAP (Energy Sector Management Assistance Program). 2022. *Mini-Grids for Half a Billion People*. Washington, DC: World Bank..

Chapter 12

Adom, D., and S. Amoako. 2019. "Community Engagement in Africa's Bioeconomy: Strategies and Impacts." *Sustainable Development Journal* 27 (4): 698–709.

Aidoo, R., E.M. Kwofie, K. Glatzel, and J. Ecuru. 2023." Bioeconomy: A Path to African Food System Transformation." In *African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, Chapter 10, 173–188. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI).

Asafu-Adjaye, J., and C. Mahama. 2019. "Political and Economic Challenges in Africa's Bioeconomy Development." *World Development* 122: 240–252.

AUC (African Union Commission). 2024a. *4th CAADP Biennial Review Report 2015–2023*. Addis Ababa, Ethiopia: AUC.

AUC. 2024b. *Second Ten Year Implementation Plan (2023 – 2033) of the Agenda 2063*. Addis Ababa, Ethiopia: AUC. https://www.nepad.org/publication/agenda-2063-second-ten-year-implementation-plan-2024-2033.

AUC. 2023. *The African Leaders Nairobi Declaration on Climate Change and Call to Actio*n. African Climate Summit 2023, Addis, Ababa, Ethiopia, September 8.

AUC. 2022. *Climate Change and Resilient Development Strategy and Action Plan 2022-2032*. Addis Ababa, Ethiopia: AUC.

AUC. 2022. *3rd CAADP Biennial Review Report 2015–2021*. Addis Ababa, Ethiopia: AUC.

AUC. 2021. *African Union Green Recovery Action Plan 2021-2027*. Addis Ababa, Ethiopia: AUC.

AUC. 2020. Biennial Report to the AU Assembly on implementing the June 2014 Malabo Declaration. The 2nd Report to the February 2020 Assembly. Addis Ababa, Ethiopia: AUC.

AUC. 2018. Inaugural Biennial Report to the AU Assembly on implementing the June 2014 Malabo Declaration. The 2017 Report to the January 2018 Assembly. Addis Ababa, Ethiopia: AUC.

AUC. 2015. *Agenda 2063: The African We Wan*t. African Union Commission. Addis Ababa, Ethiopia: AUC.

AUC. 2014. *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods Doc. Assembly/Au/2(Xxiii)*. Addis Ababa, Ethiopia: AUC.

AUC and OECD (Organisation for Economic Co-operation and Development). 2022. *Africa's Development Dynamics 2022: Regional Value Chains for a Sustainable Recovery*. Addis Ababa, Ethiopia: AUC; Paris: OECD Publishing. https://doi.org/10.1787/2e3b97fd-en

Badu, E., and G. Boateng. 2022. "Analyzing the Effectiveness of Bioeconomy Policies in Africa: Insights from Agenda 2063 and the Malabo Declaration." *Policy and Governance Journal* 8 (3): 45–58.

Beesigamuka, P., S. Subramanian, and C.M. Tanga. 2022. "Sustainable Insect-Based Organic Fertilizers for Circular Agriculture." *Journal of Environmental Management* 303: 113825.

CEEAC (La Communauté Économique des États de l'Afrique Centrale). 2021. *Plan Stratégique Indicatif à Moyen Terme (2021-2025) de la Communauté Économique des états de L'Afrique Centrale*. Libreville, Gabon: CEEAC.

Chen C., I. Noble, J. Hellmann, J. Coffee, M. Murillo, and N. Chawla. 2023. Notre Dame, IN: University of Notre Dame.

Christensen C.M., E. Ojomo, and K. Dillon. 2019. *The Prosperity Paradox: How Innovation Can Lift Nations Out of Poverty*. New York: Harper Business.

D'Amato, D., and J. Korhonen. 2021. "Integrating the Green Economy, Circular Economy and Bioeconomy in a Strategic Sustainability Framework." *Ecological Economics* 188 (2021): 107143.

EAC (East African Community). 2016. *East African Community Vision 2050. Regional Vision for Socioeconomic Transformation and Development.* Arusha, Tanzania, February 2016

EAC. 2022. *The East African Regional Bioeconomy Strategy: 2021/22 - 2031/32*. Arusha, Tanzania: EAC.

ECOWAS (Economic Community of West African States). 2022a. *ECOWAS Regional Climate Strategy and Action Plan (2022-2030)*. Abuja, Nigeria: ECOWAS.

ECOWAS. 2022b. *ECOWAS Vision 2050-ECOWAS of The Peoples: Peace and Prosperity for All*. Abuja, Nigeria: ECOWAS.

ECOWAS. 2012. *Forty-first Ordinary Session of the ECOWAS Authority of Heads of State and Government. Final Communique*. Yamoussoukro, Côte d'Ivoire: ECOWAS.

ECOWAS. 2011. *The ECOWAS Policy on Science and Technology (ECOPOST)*. Abuja, Nigeria: ECOWAS.

Ecuru, J. 2020. "Why East Africa Chose to Develop a Regional Bioeconomy Strategy." *Rural21 Op-ed*, June 26. https://www.rural21.com/fileadmin/downloads/2020/en-02/rural2020_02-S34-35.pdf

Ecuru, J., E. MacRae, and C. Lang. 2022. "Bioeconomy: Game Changer for Climate Action." *Nature* 610: 630. https://doi.org/10.1038/d41586-022-03405-0

Ellen MacArthur Foundation. 2019. *Completing the Picture: How the Circular Economy Tackles Climate Change*. Isle of Wight, UK: Ellen MacArthur Foundation.

FAO (Food and Agriculture Organization of the United Nations). 2021. *Food and Agriculture Organization of the United Nations Strategic Framework 2022-31*. Rome: FAO.

Gatune, J., N. Ozor, and R. Oriama. 2021. "The Futures of Bioeconomy in Eastern Africa." *Journal of Futures Studies* 25 (3): 1–14.

Geissdoerfer, M., P. Savaget, N.M.P. Bocken, and E.J. Hultink. 2017. "The Circular Economy – A New Sustainability Paradigm? *Journal of Cleaner Production* 143: 757–768.

Gonçalves Castro, C., A. Hofmann Trevisan, D.C.A. Pigosso, and J. Mascarenhas. 2022. "The Rebound Effect of Circular Economy: Definitions, Mechanisms and a Research Agenda." *Journal of Cleaner Production* 345: 131136. https://doi.org/10.1016/j.jclepro.2022.131136
Growth Lab. 2024. "The Atlas of Economic Complexity." https://atlas.cid.harvard.edu/

IRENA (International Renewable Energy Agency). 2023. "Kenya Spearheads Landmark Renewable Energy Initiative at Africa Climate Summit." *IRENA News*, September 4. https://www.irena.org/News/pressreleases/2023/Sep/Kenya-Spearheads-Landmark-Renewable-Energy-Initiative-at-Africa-Climate-Summit

IACGB (International Advisory Council on Global Bioeconomy). 2024. *Bioeconomy Globalization: Recent Trends and Drivers of National Programs and Policies*. Berlin: IACGB. https://www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/52440fb0-f35d-11ee-9ed1-dead53a91d31/current/document/Global_Bioeconomy_-_April_2024_IACGB.pdf

Kamarulzaman, N.H., and R.A. Mostafa. 2020. "Exploring the Potential of Bioeconomy in Africa: Lessons from Malaysia." *Bioeconomy Journal* 4 (3): 123–135.

Kansiime, M.K., I. Rwomushana, and I. Mugambi. 2023. "Fall Armyworm Invasion in Sub-Saharan Africa and Impacts on Community Sustainability in the Wake of Coronavirus Disease 2019: Reviewing the Evidence." *Current Opinion in Environmental Sustainability* 62: 101279.

Kirchherr, J., D. Reike, and M. Hekkert. 2017. "Conceptualizing the Circular Economy: An Analysis of 114 Definitions." *Resources, Conservation & Recycling* 127: 221–232.

Makokha, M. P., Muliro, P. S., Ngoda, P. N., Ghemoh, C. J., Xavier, C., & Tanga, C. M. 2023. "Nutritional Quality of Meat from Hen Fed Diet with Full-Fat Black Soldier Fly (Hermetia illucens) Larvae Meal as a Substitute to Fish Meal." *Journal of Functional Foods* 101: 105430. https://doi.org/10.1016/j.jff.2023.105430

Makoni, M. 2021. "Bioeconomy and Sustainable Development: Case Studies from Southern Africa." *Journal of Sustainable Development in Africa* 23 (2): 45–60.

Malabo Montpellier Panel. 2022a. *Nature's Solutions: Policy Innovations and Opportunities for Africa's Bioeconomy Report*. Kigali, Rwanda: Malabo Montpellier Panel.

Malabo Montpellier Panel. 2022b. *Harnessing the Bioeconomy for Sustainable Development in Africa*. Kigali, Rwanda: Malabo Montpellier Panel.

Mensah, P., and F. Enu-Kwesi. 2022. "Integrating Agriculture, Industry, and Education for a Sustainable Bioeconomy in Africa." *Journal of Cleaner Production* 315: 128276.

Mockshell, J., S. Ogutu, D. Alvarez, T. Ritter, J. Steinke, R. Remans, and M. Quintero. 2023. *Transitioning to Agroecological Food Systems: A Review of Incentives for Adoption of Agroecological Practices and Outcomes*. Cali, Colombia: Bioversity International and the International Center for Tropical Agriculture (CIAT).

Nath, P.C., A. Ojha, S. Debnath, M. Sharma, P.K. Nayak, K. Sridhar, B.S. Inbaraj. 2023. "Valorization of Food Waste as Animal Feed: A Step towards Sustainable Food Waste Management and Circular Bioeconomy." *Animals* 13: 1366. https://doi.org/10.3390/ani13081366

Nigeria, National Assembly of the Federal Republic of Nigeria, 2019. *Amendment of the National Biosafety Management Agency Act, 2019*. Abuja, Nigeria: National Assembly of the Federal Republic of Nigeria. https://nbma.gov.ng/wp-content/uploads/2021/04/Amendment-of-NBMA-Act-2019.pdf

Nwozor, A., G. Owoeye, O. Olowojolu, M. Ake, S. Adedire, and O. Ogundele. 2021. “Nigeria’s Quest for Alternative Clean Energy through Biofuels: An Assessment.” *IOP Conference Series: Earth and Environmental Science* 655: 012054

Ochieng, J., and E. Onyango. 2021. “Evaluating Bioeconomy Strategies in Africa: Successes, Challenges, and the Way Forward.” *Bioeconomy Journal* 4 (4): 212–225.

Okafor, A. 2021. “Cross-sectoral Approaches to Bioeconomy: Lessons from African Experiences.” *Bioeconomy Journal* 4 (1): 88–99.

Ombelet, L., L. Lewis, K. Kelly, and A. Gorbushina. 2024. “How Cacao Can Do So Much More Than Make Chocolate.” *WRI Insights*, February 13. https://www.wri.org/insights/hidden-benefits-cacao-waste.

Palahí, M., M. Pantsar, R. Costanza, I. Kubiszewski, J. Potočnik, M. Stuchtey, et al. 2020. *Investing in Nature as the True Engine of Our Economy: A 10-point Action Plan for a Circular Bioeconomy of Wellbeing.* Joensuu, Finland; European Forest Institute (EFI). http://doi.org/10.36333/k2a02

Poku, K., and R. Birner. 2022. “Challenges and Opportunities in Implementing Bioeconomy Policies in Africa.” *African Journal of Agricultural Research* 17 (4): 89–102.

Piñeiro, V., J. Arias, J. Dürr, P. Elverdin, A.M. Ibáñez, A. Kinengyere, C.M. Opazo, et al. 2020. “A Scoping Review on Incentives for Adoption of Sustainable Agricultural Practices and Their Outcomes.” *Nature Sustainability* 3: 809–820. https://doi.org/10.1038/s41893-020-00617-y

SADC (Southern African Development Community). 2020a. *Southern African Development Community Vision 2050: One Region. 16 Nations. Towards a Common Future*. Gaborone, Botswana: SADC Secretariat.

SADC. 2020b. *Southern African Development Community (SADC) Regional Indicative Strategic Development Plan (RISDP) 2020–2030*. Gaborone, Botswana: SADC Secretariat.

SADC. 2015. *Green Economy Strategy and Action Plan for Sustainable Development*. Gaborone, Botswana: SADC Secretariat.

Teye, E., and A. Owusu. 2021. “Specific Pathways for Bioeconomy Development: An African Perspective.” *Journal of Environmental Management* 285: 112143.

UN (United Nations). 2012. *Report of the United Nations Conference on Sustainable Development: Rio de Janeiro, Brazil, 20-22 June 2012*. New York: UN.

UNEP (United Nations Environment Programme). 2010. *Green Economy: Developing Countries Success Stories*. Nairobi, Kenya: UNEP.

UNEP. 2011. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. Nairobi, Kenya: UNEP. www.unep.org/greeneconomy

Winans, K., A. Kendall, and H. Deng. 2017. “The History and Current Applications of the Circular Economy Concept.” *Renewable and Sustainable Energy Reviews* 68: 285–833. Elsevier. https://doi.org/10.1016/j.rser.2016.09.123

World Bank. 2020a. *African Continental Free Trade Area: Economic and Distributional Effects*. Washington, DC: The World Bank. https://openknowledge.worldbank.org/server/api/core/bitstreams/ef1aa41f-60de-5bd2-a63e-75f2c3ff0f43/content

World Bank. 2020b. *Bioeconomy: Enabling the Transition to a Resilient and Sustainable Economy*. Washington, DC: World Bank.

World Bank. 2023. Multidimensional Poverty Measure database (6th edition, circa 2018). Last updated January 25, 2024. https://prosperitydata360.worldbank.org/en/dataset/WB+MPM#:~:text=The%20Multidimensional%20Poverty%20Measure%20(MPM,the%20%242.15%20international%20poverty%20line

Yaro, J.A., and A. Doku. 2020. “Social and Cultural Dimensions of Bioeconomy Policies in Africa.” *Bioeconomy and Development* 6 (2): 175–190.

Featured Issue 2

CDP. 2024a. “CDP.” Accessed September 2024. www.cdp.net

CDP. 2024b. “Rising Disclosure Numbers Show More Companies Considering Climate and Nature Impacts, but Just under 400 Reporting Data Aligned with CDP’s Highest Benchmark.” February 6. https://www.cdp.net/en/articles/companies/scores-press-release-2023

Deconinck, K., M. Jansen, and C. Barisone. 2023. “Fast and Furious: The Rise of Environmental Impact Reporting in Food Systems.” *European Review of Agricultural Economics* 50 (4): 1310–1337.

EU (European Union). 2022. “Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 Amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as Regards Corporate Sustainability Reporting,” OJ L 322, 16.12.2022, p. 15–80. http://data.europa.eu/eli/dir/2022/2464/oj

ISO (International Organization for Standardization). 2006a. “ISO 14040: Environmental Management—Life Cycle Assessment—Principles and Framework.” Geneva, Switzerland. https://www.iso.org/standard/37456.html

ISO. 2006b. “ISO 14044: Environmental Management—Life Cycle Assessment—Requirements and Guidelines.” Geneva. https://www.iso.org/standard/38498.html

OECD (Organisation for Economic Co-operation and Development) and WEF (World Economic Forum). 2023. “Emissions Measurement in Supply Chains: Business Realities and Challenges.” WEF white paper. https://www.weforum.org/publications/emissions-measurement-in-supply-chains-business-realities-and-challenges/

Science-Based Targets. 2024a.“Science-Based Targets.” Accessed September 2024. https://sciencebasedtargets.org

Science-Based Targets. 2024b. “SBTi Doubles Corporate Climate Validations in One Year as Scale Up Gathers Pace.” January 30. https://sciencebasedtargets.org/news/sbti-scale-up-gathers-pace

WBCSD (World Business Council for Sustainable Development) and WRI (World Resources Institute). 2004. *The Greenhouse Gas Protocols: A Corporate Accounting and Reporting Standard, Revised Edition*. Geneva, Switzerland and Washington, DC, United States. https://ghgprotocol.org/corporate-standard

Chapter 13

AfDB (African Development Bank). 2017. *African Economic Outlook 2017: Entrepreneurship and Industrialisation*. AfDB Reports. Abidjan, Côte d’Ivoire: African Development Bank. http://dx.doi.org/10.1787/aeo-2017-en

AUC (African Union Commission). 2014. *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC. 2018. *Inaugural Biennial Review Report of the African Union Commission on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC. 2020. *Second Biennial Review Report of African Union Commission on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC. 2022. *Third Biennial Review Report of AUC on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC. 2024. *Fourth Biennial Review Report of AUC on the Implementation of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia: AUC.

AUC and NEPAD (New Partnership for Africa’s Development). 2015. The CAADP Results Framework 2015–2025. Addis Ababa, Ethiopia: AUC. https://au.int/sites/default/files/documents/41425-doc-31250-doc-the_caadp_results_framework_2015-2025_english_edited_1-1.pdf

AUDA-NEPAD. 2022. “NAIP and RAIPs Status and Implementation for the Delivery of the Malabo Declaration.” Final Communique. Dakar, Senegal, July 26–28.

Badiane, O., J. Collins, and J.M. Ulimwengu. 2020. “The Past, Present, and Future of Agriculture Policy in Africa.” In *2020 ATOR: Sustaining Africa’s Agrifood System Transformation: The Role of Public Policies*, edited by D. Resnick, X. Diao, and G. Tadesse, G, 9–25. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: International Food Policy Research Institute (IFPRI).

Benin, S. 2016. “Impacts of CAADP on Africa’s Agricultural-led Development.” IFPRI Discussion Paper 1553. IFPRI, Washington, DC. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130647

Benin, S., J. Ulimwengu, G. Matchaya, T. Makombe, M. Lorka, A. Vodounhessi, and W. Tefera. 2018. “Mutual Accountability in CAADP and Agricultural Transformation.” In *Africa Agriculture Status Report: Catalyzing Government Capacity to Drive Agricultural Transformation*, Issue 6, 150–184. Nairobi: Alliance for a Green Revolution in Africa (AGRA).

Benin, S., M. Johnson, and B. Omilola. 2010. “Monitoring and Evaluation (M&E) System for the Comprehensive Africa Agriculture Development Programme (CAADP).” ReSAKSS Working Paper 6. Regional Strategic Analysis and Knowledge Support System (ReSAKSS), Washington, DC.

Collins, J., T. Makombe, W. Tefera, and A. Wambo Yamdjeu. 2022. “Tracking Key CAADP Indicators and Implementation Processes.” In *2022 ATOR: Agrifood Processing Strategies for Successful Food Systems Transformation in Africa*, eds. C. Jenane, J.M. Ulimwengu, and G. Tadesse, 113–136. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: IFPRI.

Collins, J., W. Tefera, and A. Wambo Yamdjeu. 2023. "CAADP Trends and Implementation Processes." In *2023 ATOR: African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, 228–246. Kigali, Rwanda: AKADEMIYA2063; Washington, DC: IFPRI.

FAO (Food and Agriculture Organization of the United Nations). 2017. *The State of Food Security and Nutrition in the World 2017.* Rome: FAO. https://openknowledge.fao.org/items/0f85cf59-0370-461b-9481-f0f708ed024d

FAO. 2024. FAOSTAT database. Accessed August 2, 2024. https://www.fao.org/faostat/en/#data

FAO and AUC. 2021. *Framework for Boosting Intra-African Trade in Agricultural Commodities and Services*. Addis Ababa, Ethiopia: AUC. https://doi.org/10.4060/cb3172en

IFPRI. 2019. "Statistics on Public Expenditures for Economic Development (SPEED)." Harvard Dataverse database. Accessed July 24, 2024. https://doi.org/10.7910/DVN/MKX1TU

IFPRI. 2024. "Vulnerability to Global Market Shocks V.2: Price Shocks to Major Staple Foods." Accessed August 31, 2024. https://www.foodsecurityportal.org/node/2505

IFPRI. 2017. *2017 Global Food Policy Repor*t. Washington, DC: IFPRI. https://www.ifpri.org/publication/2017-global-food-policy-report

ILO. 2024. ILOSTAT Data. Accessed July 22, 2024. https://ilostat.ilo.org/data/

Matchaya, G., M. Yade, P. Guthiga, W. Tefera, and A. Wambo Yamdjeu. 2022. *Policy and Programmatic Changes Resulting from the Biennial Reviews and Agriculture Joint Sector Reviews under the Comprehensive Africa Agriculture Development Programme (CAADP).* 2021 CAADP Third Biennial Review Brief: Africa-Wide. Pretoria, South Africa: Regional Strategic Analysis and Knowledge Support System (ReSAKSS); Kigali, Rwanda: AKADEMIYA2063.

Olivetti, E., J. Collins, S. Odjo, and D.D. Laborde. 2023. "Intra-African Agricultural Trade: Recent Trends and Nutritional Content." In A*frica Agriculture Trade Monitor 2023*, eds. S. Odjo, F. Traoré, and C. Zaki, Chapter 3, Pp. 69–104. Kigali, Rwanda; AKADEMIYA2063; Washington, DC: IFPRI.

Ulimwengu, J.M., G. Matchaya, T. Makombe, and J. Oehmke. 2020. "Mutual Accountability in African Agricultural Transformation." In *2020 ATOR: Sustaining Africa's Agrifood System Transformation: The Role of Public Policie*s, eds. D. Resnick, X. Diao, and G. Tadesse, 182–194. Kigali: AKADEMIYA2063; Washington, DC: IFPRI. https://doi.org/10.2499/9780896293946

Ulimwengu, J.M., W. Tefera, and A. Wambo Yamdjeu. 2023. "Seven Years of Implementation of the Malabo Declaration: Making Sense of the Malabo Theory of Change." In *2023 ATOR: African Food Systems Transformation and the Post-Malabo Agenda*, eds. J.M. Ulimwengu, E.M. Kwofie, and J. Collins, 7–35. Kigali: AKADEMIYA2063; Washington, DC: IFPRI. https://www.resakss.org/sites/default/files/2023_ator_individual_chapters/Chapter%202_ReSAKSS_AW_ATOR_2023.pdf

UNCTAD (United Nations Conference on Trade and Development). 2024. UNCTADSTAT. Accessed August 9, 2024. https://unctadstat.unctad.org/datacentre/

World Bank. 2024. World Development Indicators (WDI). Accessed August 5, 2024. https://databank.worldbank.org/source/world-development-indicators

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