CHAPTER 10

Bioeconomy: A Path to African Food Systems Transformation

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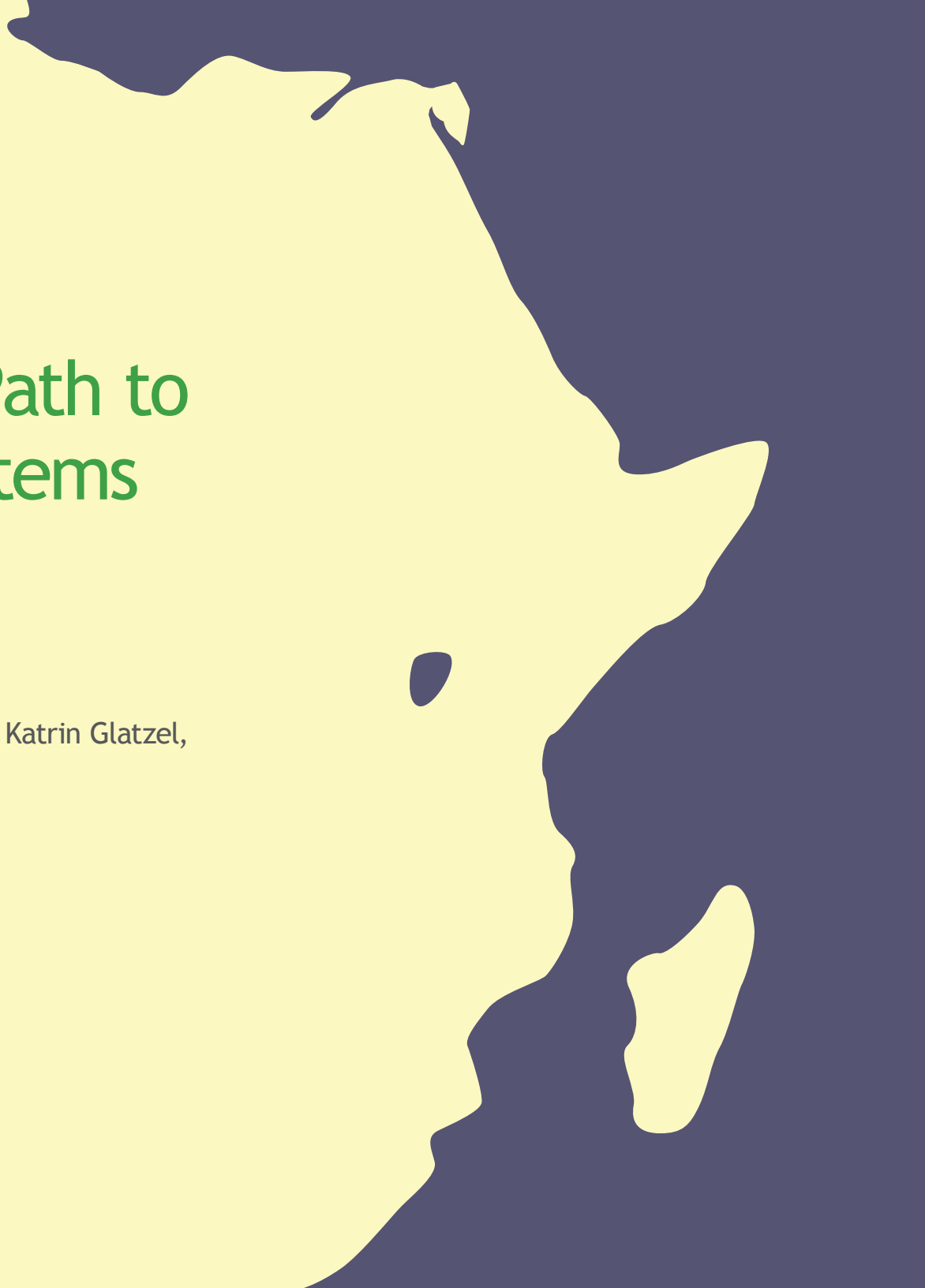


Background

Over the years, Africa's food systems have contributed to social and economic growth, creating avenues for job creation and employment, satisfying regional food and nutritional needs, promoting industrialization, and generating revenue to support regional efforts to advance and thrive. Currently, the food system employs more than 60 percent of Africa's labor force, with agriculture alone employing more than 225 million smallholder farmers, enhancing livelihoods and contributing to poverty alleviation (African Development Bank 2023; Galal 2023). Moreover, approximately 15–35 percent of Africa's gross domestic product originates from food systems activities, which are projected to increase in response to rapidly expanding agricultural activities (World Bank 2018). These contributions and the progressing dependence of the local economy on the food system amid increasing urbanization, demographic changes, and dynamics in consumer demands call for a transformation of Africa's food systems for increased resilience and continuous economic growth. While this food systems transformation agenda evolves, knowledge of the interlinkage between food system practices and the global sustainability crisis has revised the paradigm. Thus, the African food systems transformation agenda is currently restructured to run as a facilitative action that fosters resilience and supports economic and social growth without compromising efforts for intergenerational ecosystem conservation, that is, to enhance resource availability while supporting human and ecosystem health (Malabo Montpellier Panel 2022; APHRC 2021).

The complexity, overlapping and interlinked challenges, and heterogeneity of the food system mean there is no silver bullet to improving its sustainability. However, among the plethora of feasible solutions, bioeconomy has been marked 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 bioeconomy has evolved, and the current metadiscourse positions it as a growth pattern that applies science, technology, and innovation (STI) for the sustainable production and valorization of biological resources and the creation of innovative products, processes, and biodiversity services across economic sectors (Kruger et al. 2020; Bugge, Hansen, and Klitkou 2016). Bioeconomy adoption is rapidly progressing globally due to the potential benefits of growth and sustainability in agricultural systems. Its global economic potential is valued at US$7.7 trillion[1] between now and 2030. Also, successful adoption is expected to promote industrialization and social change while minimizing planetary damage (von Braun et al. 2023; Ronzon et al. 2020). Some regions, such as the European Union, have already charted significant successes in bioeconomy adoption, with approximately 17.5 million new jobs generated and €614 billion accrual of value added in 2017 (Ronzon et al. 2020). Similar trends are noted for North America and Asia, which are advancing practices for the favorable social and economic benefits that bioeconomy attaches to their green economy pursuits (von Braun et al. 2023; Patermann and Aguilar 2018).

These discussions emphasize the prospects of the bioeconomy, encouraging Africa to embrace the concept in its sustainable food systems transformation agenda. Improved bioeconomy adoption can contribute to food and nutrition security, energy security, and economic and social growth. It could enable strategic policies and initiatives to align Africa's food systems transformation with local and global sustainable development commitments (Ronzon et al. 2020). The production and utilization of bioresources are not entirely new to the African continent. For instance, Africa has been a central agricultural hub, contributing immensely to the production, consumption, and export of major biomass such as cassava, yam, cocoa, coffee, sugarcane, cashew, livestock, and poultry (Erdaw 2023; Amole et al. 2022). Moreover, analysis of aggregated and regional economic data demonstrates Africa's agriculture and agrifood system as a core driver of economic growth (Fields 2023). These data reveal a regional readiness and potential to kick-start actions toward reinforcing continental bioeconomy engagement. Recent reports emphasize a growing interest in bioeconomy adoption in Africa, with structural reorientation, policies, and strategic actions leading efforts to accelerate practice (Malabo Montpellier Panel 2022; Ariom et al. 2022; East African Community 2022). For instance, South Africa, East Africa, and some parts of West Africa are promoting bioeconomic actions, including developing dedicated bioeconomy policies or strategies. However, actual fiscal investments are relatively low. Progress in some of these subregions has proliferated interest, prompting national and regional efforts to harmonize geographic advantages in bioresource abundance, research potentials, policies, innovations, and favorable

1 All dollars are US dollars.

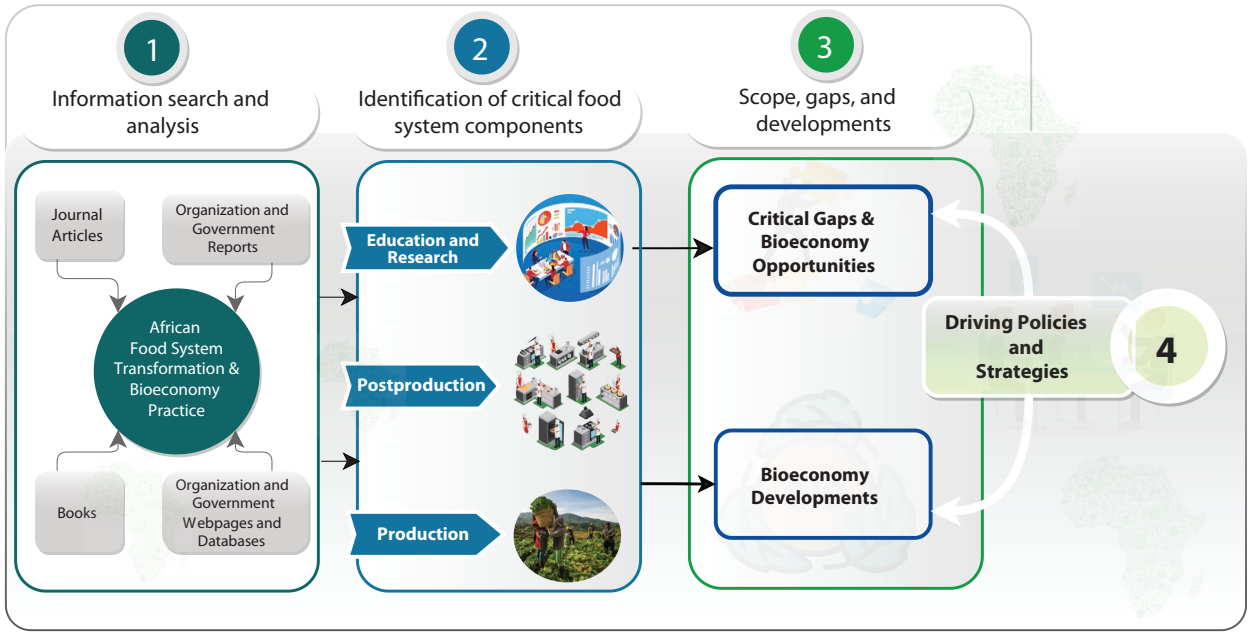
demographic dynamics into designing and implementing bioeconomy models for a more sustainable food systems transformation (Bracco et al. 2018; Gatune, Ozor, and Oriama 2021; Oguntuase and Adu 2020).

In this chapter, we intend to ascertain the current direction of the African bioeconomy pursuit and identify the opportunities for advancing regional adoption and practice to augment the sustainability of the food system. The chapter is structured into three major parts. The first part briefly elaborates on the critical components of the African food system, highlighting current practices, systemic gaps, and bioeconomic actions driving revolutions in these components. The second part entails a region-wide overview of existing and emerging policies, strategies, and commitments to promote bioeconomy practice. The third and concluding part consolidates thoughts from local and global practice to underscore feasible recommendations for regional bioeconomy practice toward sustainable food system transformation. Figure 10.1 provides a graphical summary of the structural flow of this chapter. The findings in this chapter will be of regional interest, especially to African governments, policymakers, the private sector, development institutions, researchers, and other food system stakeholders interested in developing and implementing a robust bioeconomy framework for Africa's food system transformation and overall economic development.

Critical Gaps and Bioeconomy Solutions in the African Food System

One strategy for successful bioeconomy adoption is the regional assessment of systemic gaps (Lühmann and Vogelpohl 2023; McCormick and Kautto 2013; Ronzon et al. 2020). Thus, understanding the current gaps in the African food system should be a priority in efforts toward successful bioeconomy adoption and practice. In this section, gaps in the African food system are discussed under three critical components, namely, research and education, production, and postproduction, guided by the classification of the food system wheel described by the Food and Agriculture Organization of the United Nations (FAO) (Nguyen 2018; APHRC 2021; Mitchell et al. 2021). Additionally, this section expounds on relevant regional bioeconomy pursuits to showcase how bioeconomy is being engaged to address the identified gaps.

FIGURE 10.1—STRUCTURAL FLOW OF THE CHAPTER



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Research and Education Gaps

Food system education entails augmenting knowledge acquisition, distribution, and practical implementation that drive the food system's health, sustainability, and resilience (Valley et al. 2020; Ebel et al. 2020). It follows conventional knowledge- and skill-dissemination methods, including

developing and formalizing suitable curricula to enhance availability and access to food system knowledge and expertise. This formalized-curricula approach includes the theory-dominant curricula and the technical and vocational education and training curricula (Valley et al. 2020; Kirui and Kozicka 2018). The second method is through collaborative research, where experts or groups of interested stakeholders endeavor to diagnose the food system, gather information and evidence, and explore discoveries that can reshape policy actions and instigate innovations toward sustainable transformation (den Boer et al. 2021). Next is the informal distribution of this information through skills training programs, community engagements, and other outreach and extension programs targeting relevant food system stakeholders (Parmar et al. 2019; Ma et al. 2023). Regardless of the mode of dissemination, education is recognized as a significant component for catalyzing sustainable food system transformation, taking its provisions in building capacities of the local workforce and enabling inventions, businesses, and entrepreneurship for adaptation and success (Ebel et al. 2020).

Previous investment in African food systems transformation has not adequately harnessed the power of formal and informal bioeconomy education and research, directing little attention to related developments. These untapped developments include revising academic curricula, pedagogical structures, training systems, and collaborations to align food system educational structures with evolving bioeconomic plans and visions. For instance, a broad range of food-and-agriculture-related academic programs in several academic institutions are generic, static, and theory oriented; they are limited in enhancing the problem-solving, critical thinking, leadership, ingenuity, and managerial competencies of the local human resources for contemporary innovations and strategic bioeconomy development (Agbaje 2023; Mukhwana, Kande, and Too 2017). Moreover, the few with these characteristics have also suffered significant setbacks due to fiscal, infrastructural, and policy gaps in facilitating actions. A typical example is the current deficit in investment in complementary academic facilities, limiting practical experiences and appreciation of essential theories for real-world problem solving (Daniel and Bisaso 2023; Nwosu et al. 2023). Another critical concern with food system education is the relatively low participation of public and private institutions in informal food system knowledge extension and capacity building. Outreach, extension programs, and vocational and informal training are comparatively low, leaving most smallholder farmers, small and medium enterprises (SMEs), and other bottom-level bioeconomy players with little to no knowledge about the potential of the bioeconomy, ultimately limiting their interest and active participation (Greenberg 2017). Without a quick resolve to extend and sustain bioeconomy education to these stakeholders, the evolving African bioeconomy trajectory would risk stagnancy, given the domination of these smallholder farmers, SMEs, and bottom-level players in Africa's food system. This may be partly responsible for the slow uptake slow of the bioeconomy in the African region and the mounting pressure to source external expertise for regional bioeconomy development.

Aside from the shortfalls in bioeconomy education, Africa faces a critical gap in bioeconomy research, with a few subregions—particularly South Africa, East Africa, and some West African countries—gradually setting a new research paradigm. Most research engagements struggle to transfer insights or innovations to direct policy and strategic actions for addressing challenges in food security, ecosystem conservation, and sectoral sustainability. Driving these are the low regional investment in research and related infrastructure and existing friction in academic research and industrial needs. To support food system transformation and reinvigorate the needed economic diversification, the African food system research landscape should generally evolve as a supportive system that can strengthen the uptake and transferability of research outcomes in addressing real-world food system challenges (den Boer et al. 2021). Research policies and institutions should facilitate a transition from the traditional research approach into a policy-tailored and industry-relevant process. Fortunately, the growing political will and positive institutional response signals an opportunity to expedite this agenda. Moreover, the increasing number of well-trained and connected researchers and the gradually evolving pedagogical structure would support this research revolution (Daniel and Bisaso 2023). Africa must take the educational and research revolution head-on and invest heavily in fine-tuning the current academic and research structure to facilitate a competitive, progressive, and more sustainable food system transformation culture. This should be done purposely to support training in critical thinking, problem solving, and creativity and align the regional educational forum with regional bioeconomy and food system transformation goals, wherein capacity building for small- and medium-scale farmers, young people, and businesses should be anchored in such development. Next is a more elaborate discussion of the bioeconomy research outlook in Africa.

Current Research Outlook

A traditional bibliometric analysis was conducted to visualize the bioeconomy research outlook across Africa. Following recommendations on the reliability and comprehensiveness of the Web of Science, a systematic search was performed using search terms including *bioeconomy, biobased economy,* and *Africa*, computed using Boolean OR and AND binary operators (Wang et al. 2021; Raghuram et al. 2019). The initial output of approximately 8,000 literature works was further short-listed using customized searches to exclude non-African studies, conference presentations, proceedings papers, and other literature works irrelevant to the scope and subject matter. A text file with a total of 152 literature works compiled from published books, book chapters, review articles, and original research with information on the title, authors, abstract, keywords, citation counts, country, and organizations was exported and uploaded into the VOS viewer (version 1.6.19) to ascertain the knowledge structure of the retrieved literature. The insights drawn from the bibliometric analysis are visualized in Figures 10.2 and 10.3 and further elaborated in the following subsections.

Spatial Distribution

Figure 10.2 displays a regional bioeconomy research outlook, clearly depicting country-wise densities and link strengths. The diagram shows South Africa to be leading African bioeconomy research, with strong interconnection with other regions. Nigeria, Kenya, and Ghana are gradually following suit, and other regions, such as Tanzania, Ethiopia, Zimbabwe, Botswana, Rwanda, Egypt, and Madagascar, are slowly progressing. Although the identified trend shows that the bioeconomy is not entirely new to the African economy, it adequately contextualizes continental research loopholes. An imbalance in pursuit is captured through the high concentration of research activities in South Africa. Several driving

FIGURE 10.2—SPATIAL DISTRIBUTION OF BIOECONOMY RESEARCH IN AFRICA

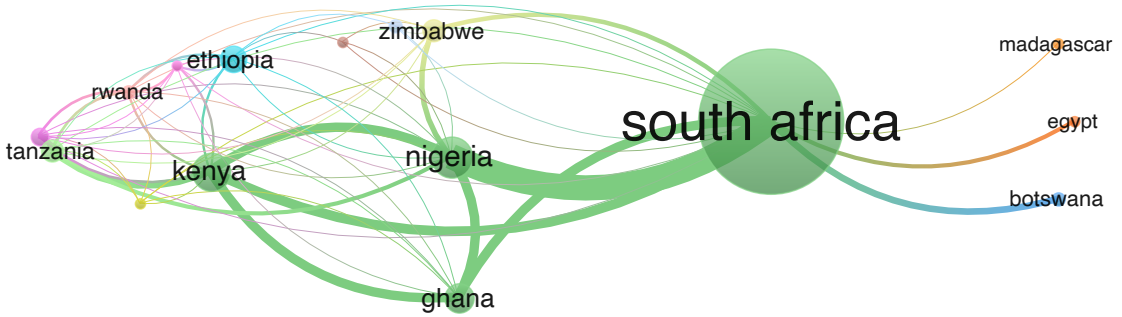

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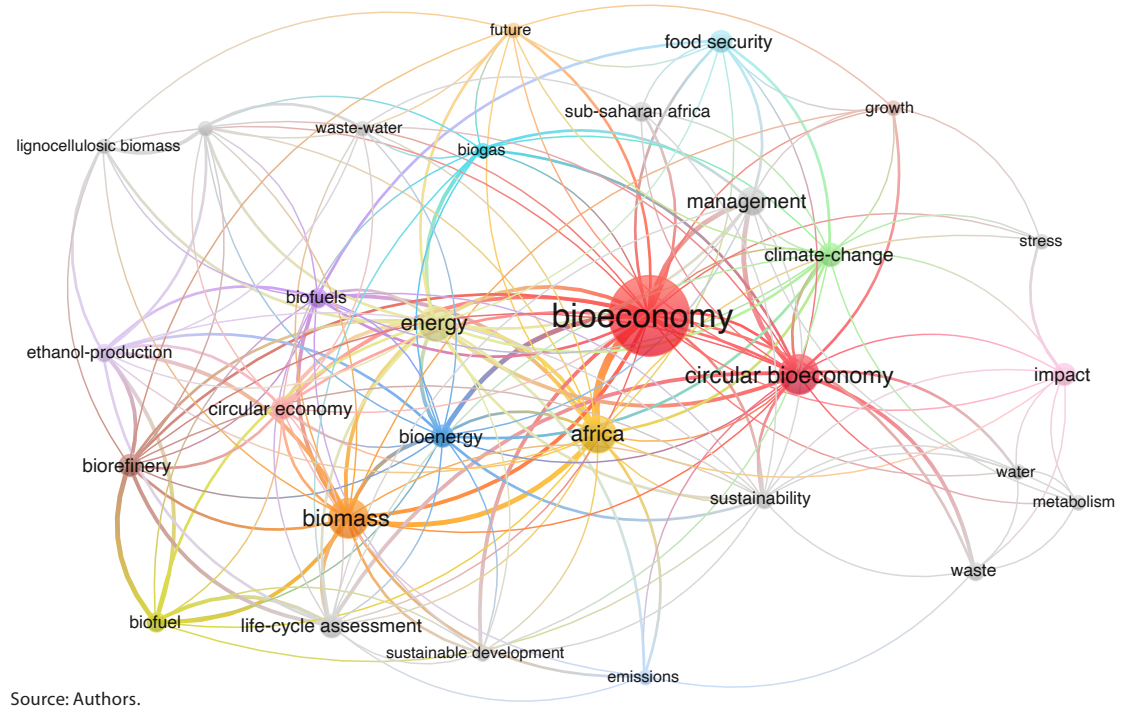
FIGURE 10.3—KEYWORDS FROM BIOECONOMY STUDIES IN AFRICA



Source: Authors.

forces could be interlinked with such disproportionality, including governmental lack of interest in prioritizing research and development (R&D) in public policies and strategies, inadequate research support from governmental and nongovernmental organizations, lack of research infrastructure and/or expertise in the field of bioeconomy, and regional variances in food system priorities. The latter presents an interesting perspective on the bioeconomy discussion in Africa, highlighting possibilities of disproportionate regional adoption subject to variabilities in economic growth priorities, geopolitical inclination, and food system strengths. For example, regions with scarcity and economic stresses may prioritize adopting a bioeconomy to revolutionize their local food systems compared to those with thriving economies. Regardless, the prudence of centralizing bioeconomy as a practical sustainability and resilience action in the evolving African food system revolution is indisputable. Beyond its vitality in addressing waste issues, its criticalness as a feasible economic regime for predisposing food value chains to regenerative thinking should be emphasized in the emerging food system agenda.

Keyword Segmentation: Direction and Perception

The use of terminologies such as *circular bioeconomy, circular economy, sustainability, sustainable development, life cycle assessment, food security, management,* and *growth,* as shown in Figure 10.3, present essential viewpoints on the direction and perception of the bioeconomy in Africa. Regarding direction, using terms such as *circular bioeconomy* and *circular economy* aligns thoughts with the increasing inclination of the bioeconomy as a circular approach in the African context. Explicably, research seems to position bioeconomy as a narrative for breaking economic systems from the dominant linear economy. It appears to be a remediative solution for reducing the linear economy's overexploitation and waste generation nature by lengthening the materials' flow loop. Moreover, there seems to be a strong interconnection between the bioeconomy, economic growth, and sustainable development goals. The prominence of terminologies such as *growth, sustainability,* and *sustainable development* justifies this context. It reinstates the promotion of bioeconomy as a promising approach for achieving sustainable economic growth. Additionally, terms such as *food security* rightly capture the notion of using bioeconomy to improve the availability, accessibility, and utilization of food in Africa.

Progress in Bioeconomy Research and Education

Africa strives to be at the forefront of knowledge acquisition, transfer, and innovations concerning bioeconomy for transforming food systems. As such, several countries have made significant steps in integrating bioeconomy education and research into their educational streams to dissolve the knowledge gap and make education beneficial to their economies. Recent efforts have led to several reformations in the African educational system and talk of the ongoing restructuring to streamline curricula; deliver practical learning experiences; and equip local human resources, including students and workers, to lead relevant innovations (Malabo Montpellier Panel 2022). In this regard, a strong aptitude has been realized in designing an array of agriculture-related programs, including undergraduate and graduate curricula in agricultural engineering, agribusiness and economics, food engineering, food technology, and food science and technology, disproportionately distributed across African higher education institutions, that engage practical pedagogical approaches in their delivery (Malabo Montpellier Panel 2022).

Moreover, national actions are being implemented to foster vital collaboration between governments, academic and research institutions, and the food industry to align educational activities with national and regional interests in reforming policies, building human capacity, and promoting industry. For example, Namibia is gradually diffusing bioeconomy education and research through joint partnerships between universities and research institutions. A typical success is the collaboration between the Namibia University of Science and Technology and the Biodiversity Research Centre, which have successfully integrated relevant conservation topics into their academic programs and developed biodiversity-related research projects of national interest. The same is noted for the University of Namibia, which has also directed efforts into expanding biobased research that explores the therapeutic advantages of certain local plants in producing functional products for local food and health applications (Malabo Montpellier Panel 2022). In Ghana, the Food Research Institute of the Council for Scientific and Industrial Research (CSIR) is advancing bioeconomy knowledge and technological transfer from collaborative research projects to stakeholders such as the food industry, farmers, and entrepreneurs as part of their ambition to accelerate the adoption of innovative processes and efficient services for food system transformation. Generally, the African outlook portrays gradually progressing commitments to enable regional competencies

in bioeconomy education and research, with a growing investment in facilities, equipment, and capacity building. However, there is a need to continually revise actions and realign engagements for education and research to constantly deliver the knowledge, competencies, and innovations needed to sustain the progress of the bioeconomy and enhance interest in related career fields.

Production Gaps

The food production and supply crisis in Africa is not unknown. Despite having the highest share of global arable land area and broad potential to expand production, Africa still faces extreme production inefficiencies, exacerbating food and nutritional insecurity, and an unstable food supply chain (Armstrong 2022; Giwa and Choga 2020). The situation interlinks strongly with several challenges, including unfavorable farm inputs, poor farm management practices, insufficient infrastructures, limitations in innovative production technologies, changing climate and land topographical dynamics, limited smallholder farmer access to services and support systems, and knowledge gaps among farmers. Gaffney and colleagues (2016) and Goedde, Ooko-Ombaka, and Pais (2019) highlight how the slow adoption of hybrid crops has interfered with the potential to maximize yield and satisfy food demands. The poultry and livestock sectors are also struggling to maintain pace with the growing global and local demand for animal-based products against a backdrop of inadequate feed production, poor market structure, inadequate investment and support systems, climate-change aggravation, and subtle herder-farmer frictions (Amole et al. 2022; Balehegn, Ayantunde, et al. 2021; Erdaw and Beyene 2022; Nkukwana 2019). A typical implication of climate change is the recent situation in East Africa, where approximately 2 million livestock were lost in a year due to recurring drought and marginal regional climate adaptation strategies (Dessalegn and Eziakonwa 2023).

While evolving trends project a tripling in food demand in Africa amid population growth and growing food insecurity (APHRC 2021; Dessalegn and Eziakonwa 2023), it is vital to innovate strategies to change current production dynamics and subvert strains on critical economic, environmental, and social boundaries as a timely action to enable a resilient, inclusive, and more sustainable regional bioeconomy. Goedde, Ooko-Ombaka, and Pais (2019) and Pius, Strausz, and Kusza (2021) project the potential to triple Africa's agricultural outputs across all commodities and increase global cereal and grains by 20 percent by increasing use of hybrid crops and fertilizer; raising investment in irrigation, storage, and other infrastructure; and improving regional trade. A regulated bioeconomy would deliver these benefits while respecting planetary boundaries (Sage 2021). The following subsections address some bioeconomic interventions to address the production challenges in Africa.

Bioeconomy in the Production Value Chain

A progressive bioeconomy plan encompasses intensified production and an adequate supply of raw materials. In this regard, several strategies have been developed in Africa to build local resource capacity for a thriving regional bioeconomy. This subsection discusses relevant production-related developments in the African food system that benefit crop yield, minimize sustainability challenges, improve farmers' livelihoods, and reinforce the capacity to supply the needed resources and services for a robust national and regional bioeconomy.

African Climate-Smart Agriculture

Climate-smart agriculture is a multibeneficial bioeconomy practice for increasing the resilience of agricultural systems amid climate change while reinforcing the capacity to catalyze national food security and economic development goals (Ariom et al. 2022). It is characterized by the potential to incorporate agriculture into social development negotiations by enabling a safe working environment for local farmers while alleviating poverty through income stability strategies. Climate-smart agriculture has gained significant traction in Africa, galvanized by the drive to enhance sustainable and regenerative agriculture. Minor but significant adaptation steps have been made by countries such as Algeria, Benin, Ethiopia, Ghana, Nigeria, Senegal, South Africa, and Zambia, with significant national variabilities in adoption rates, driven by the diversities in agricultural practices, inaccessibility to fiscal and technological resources, and other cultural factors (Persha, Stickler, and Huntington 2015). Such adaptations have popularized conservation agriculture, sustainable livestock production, forest and farmland regeneration practices, and weather and climate information services (WCIS) as effective bioeconomy practices for sustainably addressing the production, environmental, and knowledge access challenges in the African production chain.

Conservation Agriculture

Conservation agriculture entails minimizing the overexploitation of natural resources during agricultural production through integrated management approaches (Hobbs 2007; Kumawat et al. 2023). Through improved farming practices and technologies, it prioritizes the efficient use of soil, water, biological resources, and external agricultural inputs such as fertilizer and pesticides. Current practice involves minimum soil tillage, crop rotation, and cover cropping or mulching (Ariom et al. 2022). Several African countries have adopted this strategy in their agricultural systems. For instance, Benin is slowly substituting conventional farming methods with conservation agriculture, with the recent adoption and subsequent recommendation of no-tillage strategies in upland rice farming in northern Benin (Dossou-Yovo et al. 2016). Substantial benefits have been reported in net carbon loss, fertilizer use minimization, and minimized air and soil pollution using the no-tillage farming method. Similarly, Nigeria, Senegal, and Zambia have adopted conservation agriculture to address the exacerbating impacts of soil degradation and low fertilizer and pesticide inputs on crop yields and environmental pollution. Techniques such as composting, crop rotation, and no-tillage are expanding in regional adoption for their efficiency in improving crop yields even on poor soils while minimizing toxicity strains on the biosphere. In Zambia, for instance, mulching and crop rotation have been used to improve maize yield by approximately 21–38 percent. Regional adoption is widely increasing, with more than 250,000 farmers in Zambia practicing conservation agriculture (Ariom et al. 2022). Sack farming, wherein used storage sacks are used as pseudolands for vegetable farming instead of dumping, is also a prominent conservation agricultural practice in countries like Nigeria, with extended benefits in improving food availability, reducing climate impacts associated with landfilling and land use, and enhancing circular resource use systems (Ariom et al. 2022). The succulent production bioeconomy strategy is also noted in Namibia, aimed at improving soil health and increasing biomass availability by growing succulent plants on semiarid and degraded lands for food, energy, and material production (Malabo Montpellier Panel 2022). Overall, conservation agriculture has great potential to contribute to sustainable production and agricultural diversification and would benefit from increased investment and action.

Sustainable Livestock Production

Despite its low contribution to global livestock needs, African livestock production contributes significantly to global greenhouse gas emissions. For example, dairy milk production in Africa represents only 4 percent of the global market but contributes close to 10 percent of global methane emissions from the dairy industry (Balehegn, Kebreab, et al. 2021). This has triggered the increasing adoption of strategies that minimize greenhouse gas emissions from livestock production. The intent is to make livestock production as sustainable as possible to achieve bidirectional benefits in improving food and nutrition security and enhancing planetary health. Strategies such as seasonal migration of livestock into areas with natural forage and water abundance (pastoralism) (Koura et al. 2015), forage preservation for utilization in off-seasons (Jimoh et al. 2021), feed formulation from alternative feedstocks to minimize overexploitation of pasturelands and forestlands, livestock breeding programs to improve livestock resistance and productivity (Wilson 2018; Mohamed-Brahmi et al. 2022), and increased livestock health strategies such as live vaccination (Ezihe, Ochima, and Iorlamen 2020; Koura et al. 2015) are prominent bioeconomy strategies for improving sustainable livestock production in African regions. For instance, Benin, Nigeria, and Senegal are facilitating robust livestock vaccination campaigns to improve animal health and enhance production yield and quality. In addition, spatial livestock mobility practices have been adopted in these regions to manage grazing, reduce resource use, minimize demand for feedstock production, and lessen associated environmental and economic impacts. Algeria, Ghana, and Zambia also facilitate programs such as livestock breeding to enhance disease resistance and livestock growth and shift production systems that intermittently reshuffle breeds and production systems for continuous productivity. They also run an agropastoral farming system to manage grazing, minimize organic waste, and improve housing and feeding. There is also a renewed interest in biobased medicine innovations for livestock production in East Africa, wherein medicinal trees such as Prunus africana and Warburgia ugandensis are explored to deliver solutions to several livestock diseases (Virgin et al. 2022). The Kenya Agricultural and Livestock Research Organization is also leading the adoption of biobased pest and insect management techniques, such as the development of tsetse fly repellents and attractants from compound extracts from waterbuck to control tsetse fly proliferation (Virgin et al. 2022). These and many other emerging

strategies demonstrate a progressive bioeconomy adoption in regional livestock production. However, regulated regional intensification plans are needed to expand adoption and balance national success (Ariom et al. 2022; Balehegn, Kebreab, et al. 2021; Wilson 2018).

Insect Farming

In Africa, insects have historically been a bioresource for food, feed, and other nonfood or feed applications. Recently, several African countries have explored the potential of insects to address the mounting pressure on the African food system to provide adequate and accessible food/feed against the backdrop of climate change and food insecurity (Babarinde et al. 2020). More than 500 insect species are currently consumed in Africa (Smith et al. 2021). Insect farming in East Africa is promising, given the growing national interest and political will to expand it as a climate-sensitive solution to satisfy the increasing protein needs for human food, aquaculture, poultry, and livestock production. The results from a recent survey implied a strong knowledge distribution among poultry and fish farmers (70–80 percent) in East Africa (Chia et al. 2020). Likewise, more than 75 percent of farmers and feed millers were willing to adopt insect farming as a climate-smart and profitable enterprise in feed production. The favorable legal environments for insect farming in East African countries support these interests. Currently, Kenya and Uganda have approved all potential edible insect species for food and feed applications and developed well-documented legal standards to facilitate mass rearing. This is anticipated to activate millions of dollars in economic benefits and enable several upcycling streams in feed, biofertilizer, and energy production from insects and their resulting bioresidues (Tanga et al. 2021). Rwanda is following suit, with legal approval and standard development under way (Tanga et al. 2021). In West Africa, Nigeria is gradually boosting entrepreneurship across the insect value chain, with several species, including palm weevil, cricket, bee, and black soldier fly, evolving in mass rearing for food and feed production (Ibitoye, Kolejo, and Oyetunji 2019). Ghana currently hosts about nine types of insect in this trajectory, and interest in farming and consumption is high. Southern Africa is gradually building momentum in the global insect trade, with mopane worms alone holding more than $85 million in market worth (Raheem et al. 2019).

Generally, insect farming is gradually rising in Africa as a sustainable farming culture for improving protein security while creating additional revenue and employment streams for farmers and industries. In ongoing practice, Africa is supposed to generate more than $2.6 billion and $19.4 billion worth of insect-based crude protein and biofertilizer from the rearing of black soldier flies (Tanga et al. 2021; World Bank 2021). This emphasizes the growing interest in the insect farming enterprise in Africa and an opportunity to back regional advantages in species abundance by enabling the business environment, partnerships, legal standards, and investment to enhance entrepreneurial interest and guide regional propagation of interest. Regarding partnerships, international organizations such as the International Centre of Insect Physiology and Ecology, researchers, and other farmers and farmer organizations have demonstrated efforts to guide adoption and drive progress (Chia et al. 2020; Tanga et al. 2021).

Forest and Farmland Regeneration Practice

Regenerative agriculture, claimed to be a net-positive environmental and social footprint option for agricultural intensification, is a gradually evolving practice in African agriculture (Amede et al. 2023; Newton et al. 2020). Countries such as Ghana, Kenya, Senegal, South Africa, and Zambia have recently deployed regenerative agricultural solutions to regulate climate adaptation, nutrient recovery, and resource use in agriculture and forestry. Strategies such as assisted natural regeneration, a promising long-term restorative approach that combines active human planting and passive restoration in recovering forestlands and minimizing soil erosion; agroforestry (silvopasture and agrisilviculture); tree crop planting; and biobased pest and disease control and nutrient management (such as neem pesticides, biofertilizers, biopesticides) are prominent in the evolving regional bioeconomy strategies (Kpolita et al. 2022; Nyasimi et al. 2014; Virgin et al. 2022). Benin, Senegal, and Zambia are leading an agroforestry trend that has adopted the planting of trees such as Faidherbia albidia and eucalyptus trees with crop production to improve soil health and crop protection while enhancing biodiversity and farm decarbonization (Fadina and Barjolle 2018). For instance, approximately 35 percent of every 120 farmers in southern Benin are engaged in practicing agroforestry and perennial planting, leveraging their sustainability benefits in land value recovery, yield enhancement, biodiversity improvement, and carbon emission reduction. Additionally, more than 11 million Faidherbia albidia trees are distributed across the Kaffrine region in Senegal as part of their regenerative agriculture and agroforestry agenda (Nyasimi et al. 2014).

Tree crop farming is also thriving as a green resolution to combat rapid soil and land integrity loss, characteristic of the traditional annual agricultural method (Molnar et al. 2013). Herein, perennial tree crops such as cocoa, oil palm, coffee, and cashew, which are more resilient, climate adaptive, and nutrient efficient, are cultivated on landscapes, mainly to restore or maintain their integrity (Gockowski 2019). In more recent developments, practitioners are exploring mixed-production tree crop systems and integrated tree crop, animal, and/or traditional annual agricultural farming systems as more sustainable strategies for meeting the expanding food and energy needs of the rapidly increasing global population (Roberts 2017; Gockowski 2019). This farming system is gaining significant traction in modern agriculture due to its restorative advantages, such as nutrient recycling and conservation, improvement of soil structure, water management, and natural carbon cycling, as well as its potential to contribute to satisfying rapidly expanding food and energy demand (Molnar et al. 2013). Currently, approximately nine African countries, including Cameroon, Côte d'Ivoire, Ghana, Guinea, Liberia, Madagascar, Nigeria, Sierra Leone, and Togo, have adopted tree crop farming systems at various scales, fueled by supportive research, investments, and regulations (Gockowski 2019). Considering the prospect of tree crop farming and the whole regenerative agriculture trajectory in a successful bioeconomy, it is expedient for Africa to set and enforce properly designed local strategies, policies, and associated commissions and enable a public-private interaction to instigate the regional drive.

Weather and Climate Information Services

There is surging regional interest in adopting improved weather and climate information services (WCIS) and geographic information systems to optimize crop yield and resource use (Ariom et al. 2022). Some countries are leveraging the potential of WCIS in sustainable fishing and livestock breeding, while others are expanding its benefits to smallholder farmers to streamline agricultural practices and maximize productivity. In close partnership with local and international agencies, Ghana and Senegal have also launched climate information services (CIS) to augment accessibility to climate and weather information. Complementary consultation and training programs to build the adaptive capacities of smallholder farmers to climate discrepancies and extreme weather conditions are also in action. The Senegalese Institute for Agricultural Research and CGIAR World Agroforestry Center, in partnership with government extension officers, are currently using an updated version of CIS, known as the Participatory Integrated Climate Services for Agriculture, which utilizes historical climate information, participatory decision-making tools, and seasonal climate forecasts to generate exclusive climate and weather information relevant to end users (Ariom et al. 2022; CCAFS 2015; Dayamba et al. 2018). Benin also uses a geographic information system–based CIS that evaluates and integrates biophysical factors in selecting suitable watering and irrigation strategies for improved crop yields (Danvi et al. 2016). However, many other African countries have not given sufficient attention to CIS. Taking the prospects of these systems in facilitating the national bioeconomy, regions that have not yet commenced exploration are encouraged to adopt such strategies in their bioeconomy plans. Overall, trends in WCIS adoption suggest a significant digitization gap in Africa's evolving bioeconomy, presenting an opportunity to incorporate digital innovations into enhancing regional bioeconomy development. Governments, policymakers, researchers, and other food system stakeholders could prioritize these digital trends in ongoing and subsequent bioeconomy strategies to enhance agriculture, fisheries, aquaculture, and forest activities and sustain these developments in a digitally evolving world.

Postproduction Gaps

Storage, Value Addition, and Waste Recovery

Postharvest losses are enormous due to inadequate infrastructure such as transport, storage, cooling, and processing facilities. For instance, about 30–50 percent of all foods produced in Africa south of the Sahara alone do not reach consumers' tables, primarily due to poor postharvest storage. Such losses are equivalent to the caloric requirement of approximately 48 million people and about $940 billion in annual economic loss (Intelligence Report 2017; Affognon et al. 2015). Reducing these losses could contribute enormously to addressing food insecurity in Africa as well as providing farmers opportunities to engage in price negotiation and increasing incomes. A thriving continental bioeconomy would demand significant efforts to revolutionize the postharvest value chain. Innovations for energy-efficient local storage, sustainable processing, advanced infrastructures, and waste upcycling to complement such evolution in bioresource generation cannot be overemphasized (Briter Intelligence 2022). For instance, Africa operates beneath the required storage capacity, with innovations

and interventions slowly emerging due to financial and energy constraints.

Underperformance in the agro-processing sector spurs the exportation of most raw and semiprocessed agricultural outputs to advanced industrial regions and net importation of processed products at exorbitant prices into the local market. This denies Africa fiscal and social benefits that a robust value-addition chain can provide (Badiane et al. 2022). A typical example is the situation in the cocoa industry, wherein although Ghana and Côte d'Ivoire alone produce approximately 65 percent of global cocoa beans, less than 10 percent of total revenue from the cocoa value chain comes to Africa as a result of weak continental value-addition structures (Odijie 2021).

Another significant gap in the African postproduction chain concerns the underdeveloped waste value recovery component (Kissoon and Trois 2023). For instance, organic waste (food and green waste) represents approximately 40 percent of the total waste generated in Africa south of the Sahara—about 174 million tons annually as of 2016. This value is expected to triple by 2050 (Kaza et al. 2018). However, only a fraction of this waste biomass is utilized in high-value upcycling despite its vast potential for biobased food, feed, energy, and pharma products, with approximately 90 percent disposed of at uncontrolled dumpsites and landfills (United Nations Environment Programme 2018). Most African countries lack clearly defined value extraction patterns for utilizing such biomass, continually magnifying the consequences of waste generation, underutilization, and resource overexploitation on climate change, resource depletion, and biodiversity loss (Silva et al. 2023; Rubagumya et al. 2023). In the evolving African food system transformation, negotiating a revolutionary turn in postharvest storage, agro-industrial processing, and waste recovery actions would significantly advance the trajectory to promote a regional bioeconomy paradigm (Badiane et al. 2022).

Reliance on Unsustainable Materials and Energy

Until the recent surging exploration of modern energy to improve the sustainability of the gradually increasing agro-industry in a rapidly warming continent, traditional biomass has been the dominant energy source for most African small-scale industrial and household processing. For instance, in South Africa, approximately 96 percent of rural households and 69 percent of low-income urban households depend on fuelwood to cook and satisfy other energy needs (Shackleton et al. 2022). In East Africa, the rural population relies predominantly on traditional biomass such as fuelwood, animal dung, charcoal, and crop residue for more than 90 percent of total energy consumption (Wassie and Adaramola 2019). Likewise, Ethiopia sources 91 percent of its total energy demand from traditional biomass. The emerging aversion toward this current energy supply trend does not lie only in the apparent environmental impact on biodiversity, land use, and climate change boundaries but critically captures the aggravating implications on human health. For instance, indoor pollution from traditional fuel use in Kenya causes about 15,000 deaths annually of women and children, necessitating urgent intervention (Virgin et al. 2022). Aside from energy, packaging presents significant postharvest threats to the African food system. Currently, Africa consumes enormous quantities of plastics in food packaging and other economic activities, with regional annual estimates of approximately 20–32 million tons, of which synthetic plastics represent more than half of the supply (Babayemi et al. 2019; Africa Business Page 2022). This paradigm has a strong causal relationship with the rising incidence of global warming, biodiversity loss, and resource scarcity in the current African food system, connected strongly with the overexploitation of finite fossil resources for manufacturing such products.

In subsequent sustainability engagements, developing and implementing intelligent technological innovations would be necessary to cement the future of sustainable energy and plastic supply for African food systems. Unfortunately, a small percentage of investments are directed to the postproduction revolution, with current investments heavily sponsoring production intensification programs and actions. Africa needs to revise its investment and food system spending strategies. Regional investments in bioeconomy actions regarding storage innovations, sustainable material and energy production, and local value-addition strategies should be initiated, prioritizing the convergence and harmonization of intersectoral and multistakeholder capacities for radical success and growth. With these as core considerations in the ongoing transformation, several sustainability, economic, and socioeconomic benefits could be charted.

Bioeconomic Developments in the Postproduction Chain

As a complementary strategy to enhance the utilization of the increased bioresource and biomass availability stemming from improved production practices, some African regions are making quantum leaps toward adopting biobased practices and interventions (Bryne 2022; Pachón et al. 2018). This subsection discusses beneficial bioeconomy developments in the postproduction component

of the African food system. It focuses on waste valorization and storage technologies, taking their preeminence in African postharvest challenges.

Agrifood Waste Recovery Strategies

Uganda hosts Africa's pioneering—and the world's third largest—green biorefinery plant under the EU African Bio4African project, which converts locally grown elephant grass into sustainable protein feeds (Bryne 2022). This plant has presented several economic, social, and sustainable growth opportunities. Through the successful replacement of expensive soy imports with locally produced high-quality protein sources in sustainable livestock feed production, the competition between feed production and human food needs has been minimized, offering advantages in improving food and nutritional security in the region. It has also created an additional national revenue stream and stabilized income for smallholder farmers and businesses by promoting local industry and enabling the trade of often undervalued waste. A similar biorefinery is expected to be established in Ghana as part of the Bio4African project, hinting at a rapidly expanding bioindustrial system in Africa (Bryne 2022).

Conversion of biobased materials into sustainable bioplastics is profitable in derisking plastic production from exploiting finite fossil resources and associated climate and biodiversity implications. Africa is strategically exploring the potential for sustainable food packaging with increasing regional engagements and acceptance of bioplastics in green economy negotiations (Olatunji 2022). For instance, the Council for Scientific and Industrial Research of South Africa has initiated a biodegradable plastic production pathway with novel bioplastic technology currently undergoing commercial licensing (CSIR 2023). The technology is expected to enhance the national drive to reduce plastic waste burdens and minimize dependence on fossil products in food and other industrial packaging (Malabo Montpellier Panel 2022).

There is also a growing regional drive toward sustainable energy supply, with significant success charted in establishing biofuel industries. For instance, Kenya is converting a dormant petroleum refinery in Mombasa into a biorefinery that would explore national vegetable oil waste for producing more than 250 kilo tonnes (kt) of aviation fuel and hydrogenated vegetable oil diesel per year (Financial Times 2023). This can significantly minimize food system carbon emissions through its consumer waste recovery strategy and provisions for substituting fossil fuels with low-carbon-emitting biofuels. Additionally, the biorefinery is expected to create more than 400 jobs and multiple income streams upon successful completion. In addition to the refinery conversion plan, the government of Kenya is supporting the establishment of a 50-kt-per-year bioethanol plant that would also utilize agricultural waste to produce low-carbon fuels, offering similar benefits in minimizing expenditure on fossil fuel importation, expanding organic upcycling and catalyzing the decarbonization of the national agrifood system (Financial Times 2023). In Kampala, Uganda, the popular Kampala City Abattoir, in collaboration with BioInnovate Africa and scientists from Makerere University, is running a novel pilot-scale upcycling technology for converting slaughterhouse wastewater into biogas as a sustainable waste recovery strategy. The technology produces approximately 60 cubic meters of biogas per day, enabling a monthly energy cost offset of approximately $3,000, among other environmental and social benefits (Virgin et al. 2022). Clearly, Africa is making giant strides in exploring the bioeconomy for postproduction resilience and sustainable transformation. However, there is a stronger need to address the standing imbalance in regional participation through defined regional strategies and responsible distribution, capacity harmonization, and well-regulated investments.

Innovative and Emerging Storage Innovations

Several companies have recognized the vitality of developing locally adaptable innovations to curb the long-standing gap in Africa's postharvest storage landscape. In the current technological ecosystem, the dominant smallholder farmers and SMEs cannot afford the upfront cost and energy demands of securing efficient cold storage facilities, hindering adoption and exacerbating postharvest loss. In bridging these financial and energy barriers, companies such as Solar Freeze, InspiraFarms, and Sokofresh of Kenya; Coldbox Store, Koolboks, and ColdHubs of Nigeria; FreezeLink and Akofresh of Ghana; and Kivu Cold Group of Rwanda, among others, have doubled their actions toward creating sustainable storage solutions to augment postharvest storage (Briter Intelligence 2022). Adding on to these technological breakthroughs are beneficial business models to enhance farmer patronage and stabilize the incomes of smallholder farmers and businesses. In Nigeria, Koolboks, a solar refrigeration service provider, pioneered a "cooling as a service" model that allows farmers to access efficient cooling services without worrying about the exorbitant upfront cost (White and Kore 2022). Through a lease-to-own strategy prefinanced by the company, smallholder farmers and SMEs can access services of efficient storage systems and distribute

expenses across 24 months, after which they fully own the facilities. Additionally, the company provides exclusive postharvest management training to its clients to maximize storage efficiency, reduce postharvest loss, and stabilize incomes. Kivu Cold and Solar Freeze in Kenya run a similar model with varying value propositions. For instance, Solar Freeze has built mobile solar-powered cooling facilities that allow smallholder farmers and businesses in rural Kenya to access efficient cooling services at competitive prices (Briter Intelligence 2022; Kenya Climate Innovation Centre 2019). These trends promise a postharvest storage revolution to facilitate regional bioeconomy practice. However, the current trend demonstrates limitations in complementing the expected increase in production yield in a bioeconomy model, prompting regional investment into expanding existing storage innovations and models or establishing larger storage infrastructures to expedite postharvest storage actions for a successful regional food system transformation.

Bioeconomy Policies and Strategies

At this point, most African countries are in the early stages of developing the bioeconomy. However, the accelerating trend at the global level toward advancing the bioeconomy for sustainable development suggests the need to expedite actions in the African trajectory (Ronzon et al. 2020; von Braun et al. 2023). Lessons from regions such as Europe, Asia, and the United States have highlighted a strong correlation between successful practice and efforts in developing robust strategies, programmatic interventions, and radical symbiosis. These lessons emphasize the certainty of a dynamic and enabling policy environment for steering a thriving bioeconomy in Africa. A few successful bioeconomy strategies in advanced practicing regions include objective-oriented policy formulation; high investment in research, education, and innovation; multistakeholder capacity building; dynamic private-sector-mediated innovation; enabling an entrepreneurship environment; strategic bioeconomy trade and market management; and flexible regulatory framework development. By replicating, contextualizing, and scaling up these insights, African governments can develop robust and feasible frameworks that can face the complexities and diversities in practice and drive a more sustainable paradigm. A regional scan of Africa's bioeconomic development demonstrates an evolving momentum toward policy formulation and programmatic actions. Thus, this section provides a brief outlook of regional policy and strategy dynamics and highlights some relevant considerations that could stimulate success, learning from working actions in other regions.

Current Regional Policy and Strategy Outlook

The growing understanding of the prospects of long-term and stand-alone bioeconomy plans has spurred national and regional actions and renewed commitments toward developing robust bioeconomy plans, policies, or strategies that would advance participation in global biomass trade, foster integration into the global green economy, and reinforce actions toward economic and social freedom. Thus, several countries, including Ethiopia, Ghana, Kenya, Rwanda, South Africa, and Uganda, are transcending the mere integration of bioeconomic actions into general development plans, to develop stand-alone bioeconomy plans that drive properly designed policies and strategies to direct focus and accelerate short- and long-term success.

East Africa has demonstrated particular leadership, with its well-documented East African Bioeconomy Plan that captures the creation of new and improved biobased products, enhancing value addition and innovative utilization of bioresources and creating alternative sources of food and feed, health bioenergy, and ecosystem services in its scope. This plan binds East Africa's food systems transformation agenda to a defined bioeconomy model, focusing on and accelerating strategic actions to address pertinent challenges. The South African Bioeconomy Plan portrays a similar drive, positioned to contribute in a major way to the national gross domestic product by creating and growing novel industries that generate bioresources and develop biobased products, services, and innovations (East African Community 2020). Following the developments in East Africa, West Africa could leverage the growing national interest to develop a West African Bioeconomy Plan that would guide national adoption and practice and expedite progress through joint actions and partnerships. West African countries such as Ghana, Nigeria, and Senegal are already on a promising path to developing stand-alone national plans. While these segregated plans are useful, it is even more prudent and beneficial to consider bioeconomy adoption at theat the regional and continental scales. Thus, Africa should envision a continental bioeconomy plan that harmonizes national capacities into an interconnected and adaptable regional bioeconomy forum for driving a shared regional food system transformation and overall economic growth, which could be defined as a shared African bioeconomy plan.

Embedded in these bioeconomy plans are several tailored policies and strategies to drive the success of the multicomponent regional bioeconomy structure. For instance, Benin, Ghana, Namibia, Nigeria, and Senegal have developed and are pursuing tailored bioeconomy-related policies and strategic frameworks to enhance crop and animal production and sustainable utilization. In Ghana, the Ghana Shared Growth and Development (I and II, 2010–2017), Food and Agricultural Sector Development Policy (I and II), and Climate Smart Agriculture and Food Security Action Plan closely explore bioeconomy visions in sustainable food system transformation (Malabo Montpellier Panel 2022). Namibia's Vision 2030, National Biodiversity Strategies and Action Plan, and National Development Plan 5 outline patterns for modernizing agriculture, sustainably utilizing bioresources, and improving intra- and interregional trade and markets (Malabo Montpellier Panel 2022). Africa Sustainable Livestock 2050, a policy initiative for exploring attainable actions to regulate the economic, public health, environmental, and social benefits of the African livestock sector, is also at play in Burkina Faso, Egypt, Ethiopia, Kenya, Nigeria, and Uganda (FAO 2023). This agenda is steering significant success in the African livestock industry, considering improvements in production and productivity and improved investment in sectoral value chain research, innovation, and development since its inception (FAO 2020, 2021, 2022).

Also in action is the Science, Technology, and Innovation Strategy for Africa 2024, which is developing priority STI strategies to lead a knowledge-based and innovation-driven economy (Kahn 2022; van Heerden and Mulumba 2023; Makinda 2023). However, the strategy expires in 2024, making it prudent to consider the design of bioeconomy-targeted policy actions for STI development. Otherwise, such an idea could be incorporated into the renewal of the Science, Technology, and Innovation Strategy for Africa to create a definite direction for driving STI in the bioeconomy and other economic dimensions. This would enable a more tailored forum for knowledge creation and transfer, technology development, and innovations to direct a sustainable and progressive bioeconomy transition in the food, health, energy, and other sectors within the bioeconomy frame.

Sustainable Continental Bioeconomy Design

Whereas the previous sections have alluded to the potential sustainability benefits of a regional bioeconomy, it is essential to mention that the intersection of bioeconomy and sustainability is characterized by deliberate actions to deploy mechanisms and tools that would foster such sustainability (Malabo Montpellier Panel 2022; Aidoo, Romana, et al. 2023; Agyemang, Kwofie, and Baum 2022). Bioeconomy is not intrinsically sustainable; suitable approaches and decisions are required to activate and drive its sustainability potential. Thus, the discussion on bioeconomy in Africa should transcend the mere conceptual commitment to understand how to align practice with sustainability goals. Supporting this are the works of Aidoo, Kwofie, and colleagues (2023), Aidoo, Romana, and colleagues (2023), and Agyemang and colleagues (2023), which highlight the benefits of modeling and multidimensional analysis in improving the sustainability performance of intervention programs. In the authors' opinions, optimal and sustainable designs can be achieved when systems are robustly designed and tested multidimensionally. A summary of their mechanisms for sustainable policy decisions, system design, and intervention strategy involves the merger of stakeholder engagement, life cycle sustainability assessment, trade-off analysis, and multicriteria decision analysis, supported by interactive and statistical decision support frameworks and digital intelligence in optimal solution development and implementation. Engaging these mechanisms in the development of a robust African bioeconomy plan sounds promising and relevant considering their potential to enable optimal, feasible, and more sustainable bioeconomy solutions. Figure 10.4 visualizes the mechanisms that could be leveraged in developing a robust and sustainable African bioeconomy plan.

Bioeconomy Management System

A sustainable bioeconomy is as strong and relevant as the backing management system. Therefore, while regional momentum evolves toward bioeconomy development, it is vital to design and adopt a strategic management system to steer the delivery of economic, environmental, and social advantages. In this regard, important lessons can be learned from the evolution of economic management, which has emphasized the up and down sides of the two prominent management systems, top-down and bottom-up approaches, and underscored the positive interactions, compromises, and contrasts that exist for rethinking management in every system (Zuluaga et al. 2022; Kubickova and Campbell 2018; Cowell, Bissett, and Ferreira 2020).

Lessons from the current direction of economic management strongly compel the relevance of integrating the strengths of both top-level and bottom-level

FIGURE 10.4—AUGMENTING BIOECONOMY DEVELOPMENT WITH POLICY MODELING, SUSTAINABILITY ASSESSMENT, AND DIGITAL INTELLIGENCE

Source: Authors.

regional players in designing and executing a hybridized bioeconomy management system that would enable maximum participation and collaboration between public and private stakeholders, also called the co-management approach (Cowell, Bissett, and Ferreira 2020). This hybridized system could facilitate the establishment of regional public and private commissions that will harmonize their capacities in a regulated manner to drive sustainable and rapid adoption of bioeconomy. However, such a hybridized system should carefully consider the extent of stakeholder inclusion, available compromises, and geographic ideals to properly design objective-oriented policies and strategies backed by strictly enforced and flexible regulatory frameworks. In summary, subsequent bioeconomy engagements should consider the regulation of stakeholder interactions, be locally favorable, and be more objective oriented. They should also provide an enabling environment to stimulate grassroots initiatives, be appropriately coordinated, and encourage the joint emergence and diffusion of local bioeconomy innovations.

Conclusion and Recommendations

This chapter highlights the prospects of the bioeconomy in augmenting food system transformation and aligning food system actions with global sustainability commitments. It reveals critical loopholes in the African food system, underscoring significant production, postproduction, education and research, and policy gaps. Additionally, it outlines relevant

bioeconomic interventions tightly bound to changing the dynamics in these components and fostering a progressive and sustainable food system transformation. Africa has shown immense progress in bioeconomy practice, given the expanding adoption of related actions in promoting agricultural production, value addition, and the development of adaptable technologies and services to drive resilience and sustainability in the food system. However, the regional distribution of engagements is skewed to a few countries, demonstrating enormous untapped potential in many regions and encouraging the need to nudge national engagements to strengthen sustainable economic and social development.

While accelerating national adoption is vital, an adaptable regional bioeconomy approach will enable cooperation, knowledge sharing, and technology transfer and interconnect biomass availability, biobased products, and services into a common bioeconomy forum. Thus, Africa should embrace the effort to integrate competing national efforts, harmonize fragmented national strengths, and proactively address geopolitical variabilities to develop an integrated African bioeconomy plan or strategy that enables a shared regional bioeconomy drive for sustainable food system transformation and employment generation. The prospects of the recommended integrated development can be likened to the success of the European Bioeconomy Strategy, wherein the shared bioeconomy goal among European countries has driven tremendous economic success, amounting to approximately €614 billion in value added and about 17.5 million related jobs.

Developing an Africa-wide bioeconomy strategy and accelerating successful implementation would require a series of national and regional diagnostic exercises, such as discerning and addressing the forces that exist at the innovation niche, sectoral regimes, and societal landscape, alongside the participation of regional stakeholders in driving policy actions, investments, and innovations. Governments and policymakers must be willing to take a hybridized approach that allows bottom-level but dominant stakeholders such as peasant farmers, SMEs, and young entrepreneurs to contribute to strategic and relevant policy development, regulations, and strategic bioeconomy actions. The national budgets must reflect the ambitions of regional bioeconomy development and subsequent implementation, and governmental actions must be directed toward enabling the political environment for a progressive change paradigm. The private sector, nongovernmental and civil organizations, research and academic institutions, and industry must similarly cooperate and radically collaborate to develop and drive a functional system that creates and utilizes innovative biotechnologies for continuous bioresource generation and creation of sustainable services and products. These would strengthen Africa's position in the global bioeconomy paradigm.

A regional strategy also informs the need to energize the innovation system to enhance investments in education and R&D. Such a strategy should consider science, technology, engineering, and mathematics (STEM) subjects, sustainability education, technical and vocational education and training, and indigenous knowledge as integral components of a regional bioeconomy structure that empowers students, young people, farmers, and enterprises with the knowledge and practical capacities to participate meaningfully in the evolving bioeconomy practice. Africa would benefit from directing targeted regional efforts, investments, and joint actions to reinforce region-specific, bioeconomy, technical and vocational education and training. This should be tailored to facilitate the development of relevant work- or skill-based competencies to complement the dominant knowledge-oriented workforce on the continent. Also, closer collaboration between higher education, research institutions, and the private sector can be facilitated to nurture research ideas and innovations into commercially valuable forms. In this regard, enhancing the financial sustainability of national research institutes through hybrid funding models that accommodate private-sector services and international development partners would be necessary for facilitating such collaborations across sectors and among stakeholders to augment bioeconomy research design and outcomes. It is important to stress the relevance of increased investment in R&D for the evolving African bioeconomy paradigm, given the knowledge demand for a more functional bioeconomy. Prioritizing and increasing R&D investments is needed to expedite and sustain a local knowledge and innovation cycle that consistently provides the relevant insights to create and enhance a more tailored, resilient, and inclusive regional bioeconomy.

Sustaining a regional bioeconomy drive would demand flexibility to adjust and realign focus to achieve desired sustainability outcomes. This includes embracing life cycle sustainability assessment, decision analysis tools, and other digital innovations in the development and implementation of a regional bioeconomy plan. The above discussions reflect the work required in a shared African bioeconomy plan, accentuating the significance of strategic management, wherein a hybridized bioeconomy management approach is suggested. With financial commitments, collaborative efforts, increased R&D investment, and leveraging of national and global experiences, Africa will be well-equipped to design and implement an African continental bioeconomy agenda.