



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 UGGDS' 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 biore-source 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 (Lakapunnrat 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 multi-sectoral 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 Expansão 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 UNFCCC'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 multi-lateral 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.