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Implementing bioeconomy strategies and policies

Lessons from Colombia, Thailand and East Africa

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A young black woman walking across a sugarcane plantation with a hoe on her shoulder© Gloria mwivanda/Getty Images

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1. Introduction

In this working paper, we focus on the "meso level", which relates to bioeconomy strategies and their implementation. A bioeconomy strategy translates and articulates a vision for bioeconomy development at a particular jurisdictional level (e.g. subnational, national, or regional) based on review, analysis and stakeholder engagement processes. The implementation of a bioeconomy strategy generally follows a roadmap that provides concrete steps and actions appropriate to the particular institutional and organizational context at the subnational, national or regional level. The gap between strategies and their implementation tends to be more pronounced in low- and middle-income countries due to financing constraints. But even among high-income countries, implementation gaps arise especially for demand-side measures such as consumer incentives or awareness raising, whereas supply-side measures such as research and development (R&D) for bio-based innovation are more straightforward (Dietz et al., 2023). Our objective here is to gain an improved understanding of the gaps between bioeconomy strategies and their implementation.

The aim of this working paper is thus to provide an analysis on bioeconomy strategies and their implementation at the subnational, national and regional levels in Latin America, Southeast Asia and Eastern Africa. Due to the limited scope afforded in this broad study, we do not attempt to cover these regions comprehensively. Instead, we have chosen the cases based on characteristics that align to some extent with the notion of "alternative pathways" under which smaller-scale and artisanal bioeconomy approaches are considered alongside the more traditional larger-scale and/or industrial-oriented approaches. Colombia was chosen due to the recent prominence given to its bioeconomy strategy development, but also because of the importance of subnational bioeconomy strategies (referred to as "territorial" strategies in Colombia for reasons of biophysical and socio-economic heterogeneity). Thailand was chosen in Southeast Asia because of the fact that it has given prominence to both industrial and artisanal approaches to bioeconomy. East Africa was chosen as it is the only region outside the EU with a comprehensive regional-level bioeconomy strategy. Our three-region comparison thus aims for broad learning on bioeconomy strategies across levels as well as regions.

Strategy processes in Colombia, Thailand and East Africa are reviewed and analysed in successive sub-sections, including subnational cases (Colombia), national cases (Colombia and Thailand) and regional or pan-national (East Africa). In each region or case, we consider the institutional context (including policies and legal or regulatory frameworks) and the roadmap that addresses implementation issues. The overall vision embodied in a given strategy is considered based on a stakeholder analysis, drawing where appropriate on the framework provided by Bugge et al. (2016) that distinguishes biotechnology, bioresource and bioecology visions. Sustainability and inclusivity are evaluated, and where appropriate we allude to significant governance challenges. A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) is conducted in each case, and the chapter concludes with cross-regional learnings which draw particularly on the stakeholder engagements and workshops conducted in each region.

2. Colombian bioeconomy strategy and implementation

Colombia is among the world's most biodiverse countries, trailing only Brazil and Indonesia which are much larger in area and population. As with many middle-income countries, conservation in Colombia needs to be balanced with the sustainable use of biodiversity in order to avoid a cycle of resource degradation in areas where low-income communities are dependent on natural resources and ecosystem services. Colombia has thus advanced a vision and strategy of bioeconomy as an enabler of sustainable development at subnational and national levels, supported by its enormous biodiversity and significant biomass production. This section emphasizes national and subnational (or territorial) strategies by applying different bioeconomy visions across different approaches to stakeholder engagement in order to adapt bioeconomy principles to the Colombian context. A critical analysis is conducted on the implementation of the Colombian bioeconomy strategy and associated policies, and the section ends with a SWOT analysis.

2.1. Subnational perspectives on bioeconomy in Colombia

The subnational (also referred to as territorial) level is important for bioeconomy strategies in Colombia, due to significant variations in agro-ecological zones and socio-economic conditions, and the associated emphasis by the government on local involvement (Minciencias, 2023). Thus, our analysis builds on direct experience with stakeholders in two subnational cases situated in different areas of the country, each with its own distinct ecological characteristics and socio-economic priorities in relation to bioeconomy development. The first area is the Valle del Cauca, in which we co-developed bioeconomy scenarios with key actors based on different broad visions, inspired by – although somewhat different from – the "visions" identified in the academic literature by Bugge et al. (2016). The second area is the Caribbean, where stakeholder engagement was configured on the basis of the workstreams for key departments advancing the bioeconomy at the territorial level.

Bioeconomy visions for Valle del Cauca

Valle del Cauca is a region in Colombia characterized by huge biomass production related mainly to sugar cane, plantain and coffee, among other crops (Invest Pacific, 2022). It is also a remarkable biodiversity hotspot with more than 30 ecosystems (CVC, 2019). In addition, the private commercial and agro-industrial sector is well organized and highly competitive. Thus, Valle del Cauca has enormous potential to take a leadership role in bioeconomy innovation and promotion. Consequently, a workshop with key actors was held in 2020 in Cali, Valle del Cauca's capital, to assess different bioeconomy visions and build a regional roadmap for bioeconomy implementation (Canales et al., 2021a). The actors represented enterprises (agricultural and tourism sectors), government (local, regional and national), and academia.

A backcasting methodology was used in this workshop, and three broad sectors relevant for bioeconomy were considered: agricultural, agro-industrial, and nature tourism. At first, participants were asked about their broad visions for the region in 2050 related to the bioeconomy. This exercise encourages thinking big and permits "dreaming" about the future; therefore, it transcends short-term thinking and the usual governmental time period of 4 years. Once these different visions were developed, each participant was asked which objectives needed to be achieved in order to reach that vision, thinking first about the milestones to be achieved by 2050 and then going backward in time: first 2030, then 2026, and finally 2022. Thus, the steps to be followed to achieve each vision are put on paper, which were characterized according to value creation, innovation drivers and spatial focus. The results are summarized in Table 1 and Table 2.

Table 1. Results of backcasting methodology for 2050, 2030, 2026 and 2022 in Valle del Cauca, Colombia, for the selected sectors

	2050	2030	2026	2022
Agricultural	• Rigorously apply environmental regulations. • Widely use biological controllers of pest and diseases.	• Inventory species for biological control. • Establish regulations, incentives and penalties to promote the transition to biological controllers. • Produce through sustainable systems. • Strengthen training capacities in bioeconomy: sustainable agriculture, precision agriculture, provision of nature tourism services.	• Increase research and knowledge on potential uses of agricultural and agro-industrial waste. • Inventory the volume, types and uses of agricultural waste. • Expand the supply, dissemination and access to training programs for farmers in sustainable agricultural systems. • • Expand the access to training programs for farmers in entrepreneurship, associations and cooperatives.	• Increase research and dissemination of biological controllers. • Increase supply and access to sustainable agriculture training programs. • Increase supply and facilitate access to agricultural extension programs and training in sustainable agriculture.
Agro-industrial	• Continue the operation of 15 biorefineries with the production of high added value products, including green chemistry (e.g. natural ingredients and cosmetics). • Transform Buenaventura into a sustainable bioindustrial hub.	• Implement ten rural biorefineries connected at national and international level.	• Implement three rural biorefineries with biodiversity and traditional resources.	• Evaluate the feasibility of a business model to establish a biorefinery in Buenaventura.
Nature tourism	• Recover species that in 2020 had endangered status.	• Expand the implementation of payment for ecosystem services schemes for greenhouse gas capture and increasing biodiversity.	• Expand access to training and formalization of specialized nature tourism service providers.	• Evaluate the viability of payment for ecosystem services for greenhouse gas capture and increase biodiversity. • Generate institutional conditions for payment for ecosystem services for greenhouse gas capture and increasing biodiversity. • Increase supply and access to nature tourism training programs.

Source: Canales et al. (2021).

As shown in Table 1, incremental advances were forecasted for each of the sectors prioritized. Regarding the agricultural sector, the actions were centred on the use of biological controllers, the revalorization of residues and training. In the case of the agro-industrial sector, the stakeholders focused on the construction of rural biorefineries with a special interest in Buenaventura, a city near Cali, the capital of Valle del Cauca. Finally, for the nature tourism sector, the actions were focused on developing "payment for ecosystem services" schemes for greenhouse gas capture and increasing biodiversity, as well as training.

Table 2. Results of Bioeconomy Stakeholder exercise for 2050 in Valle del Cauca, Colombia, for the selected sectors and key characteristics

	Goals and objectives	Value creation	Innovation drivers	Spatial focus
Agricultural	Generating new products and achieving sustainability	Focused on research and the use of waste residues	Collaboration among the State, industry and academia as central actors, accompanied by civil society to incorporate traditional knowledge	Rural development, based on the location of resources, and linked to spaces external to the region
Agro-industrial	Generating jobs and achieving sustainability	Focused on research and the use of waste residues	Collaboration among the State, industry and academia as central actors, accompanied by civil society (whose role is smaller in this case)	Rural development, based on the location of resources, and linked to spaces external to the region
Nature tourism	Economic growth, job creation and sustainability of the sector	Using research results as a key instrument for the conservation of biodiversity	Collaboration among the State, industry, academia and civil society	Rural development, with territorial identity and global links

Source: Canales et al. (2021).

As shown in Table 2, although the goals and objectives differ among the sectors, they all aim for long-term sustainability. In addition, the actors focused on value creation through research, which is a key pillar but not the only one. For instance, they didn't recognize the potential enterprises have to create value except by their capacity for recycling waste. This might be influenced by a higher composition of actors in the workshop coming from academia than from enterprises.

Furthermore, the actors converged on recognizing the importance of cooperation among the quadruple helix: state, industry, academia and civil society. They also converged in their focus on rural development promoted by external links, whether regional or international. In summary, these visions take elements from the bioecological and bioresource visions.

To achieve these visions and the goals behind them, different actions were proposed:

- **Governance:** Governance was identified as one of the most important pillars due to the necessity of having actors leading and in charge of promoting and making possible each vision. In particular, they proposed the creation of a regional committee that leads the planning and execution of a regional vision of the bioeconomy and ensures compliance with it.

- **Financing:** Proper financing mechanisms must be designed to promote recycling, green businesses and bioproducts. In addition to designing financing mechanisms, sustainable financing sources must be identified.

- **Infrastructure:** As all the bioeconomy visions focus on rural development, current infrastructure could be a bottleneck for achievement. Thus, important investments should be made in roads (especially tertiary roads), water provision and energy infrastructure.

At a sectoral level, several activities were proposed in 2022, 2026, 2030 and 2050:

- **Agricultural:** Activities were highlighted to promote sustainable production systems, including multifunctional climate-smart models. These systems would also use sustainable inputs, such as biological controllers for pests and diseases, minimizing the use of agrochemicals. In addition, it was proposed to identify the potential of applying payment for ecosystem services and greenhouse gas sequestration schemes for agricultural systems.

- **Agro-industrial:** Promotion of rural and social biorefineries was highlighted, prioritizing short marketing circuits and local impacts. Unlike the other two sectors, specific actions were proposed, such as an economic, environmental and social feasibility study for the establishment of a lactic acid and bioplastic biorefinery based on Chinese potatoes (*Colocasia esculenta*) in the city of Buenaventura. This would serve as a leading and inspiring example for other biorefineries.

- **Nature-based tourism:** Training programs to promote the sustainable use of biodiversity for commercial, contemplative and research purposes were highlighted. These programs must include scientific knowledge and traditional knowledge.

Bioeconomy visions in the Caribbean region

The Caribbean region is one of the top agricultural producers in the country, especially for cattle, corn, cassava, rice, bananas and tubers. Paradoxically, some of the Caribbean departments are among the poorest in the country and have high levels of food insecurity (SEI, 2024c, 2024b, 2024a). As the bioeconomy promotes new business models based on the use of biomass and biodiversity and could create new income sources for local communities, it is suitable to be a sustainable development motor for the region.

Consequently, three regional workshops with key actors were held in 2024 in the Caribbean region (in departments of Sucre, Córdoba, and Bolívar) to discuss several visions around bioeconomy for 2034, 2029 and 2025. The results from the workshops, including these visions, were built and shared with the regional and local governmental authorities while they were developing the regional development plans for the next period (2024–27). The visions obtained showed the potential for bioeconomy as a development motor from the perspective of key local and regional stakeholders.

Table 3 shows the final visions for 2034 determined for each department. This set of actors involved: enterprises; local, regional and national governments; and academia. With these visions at hand, the goal was to agree on economic, environmental and social objectives to comply with the visions for the bioeconomy in the region.

Table 3. Visions for 2034 for the implementation of bioeconomy in the Caribbean region in Colombia.

Department	Vision for 2034
Sucre	Sucre envisions itself as a leading agro-industrial and agrotourism department, transitioning to a bioeconomy. The strategy focuses on sustainable value chains for key products like cassava, rice, corn, fruits, cashews, and meat, promoting food security and high-value bioproducts such as functional foods, biomaterials and bio inputs. Collaboration among producers, entrepreneurs, academia and governments will drive the implementation of sustainable, circular systems that emphasize solidarity with small producers. Agricultural waste will be repurposed into food products, biomaterials and bio inputs, bolstering the industrial sector. Science, technology and innovation will support rural development and benefit small producers, ensuring a competitive bioeconomy by 2034.
Córdoba	Córdoba envisions transitioning to a bioeconomy, focusing on sustainable value chains for products like cassava, yam, banana, palm, coconut, farmed fish, meat and dairy. The goal is to enhance food security and generate high-value bioproducts such as organic foods, bio-packaging, bio inputs and animal feed concentrates. Advanced, circular production systems powered by renewable energy will drive industrialization, creating jobs and improving the quality of life for residents. Ecosystem conservation and restoration will support climate regulation and provide vital ecosystem services, ensuring a sustainable and competitive bioeconomy.
Bolívar	By 2034, Bolívar will consolidate a sustainable, profitable and technically advanced agricultural sector. Efforts will focus on promoting associations, access to credit and business creation, ensuring food security. The bioeconomy will be embraced as a competitive, sustainable production model. To combat climate change, monocultures will be converted to sustainable systems aligned with ecosystem needs. The adoption of good agricultural and livestock practices, organic farming, renewable energy generation, and ecosystem conservation will drive innovation and transform all links of the production chains.

Source: SEI (2024a,b,c)

As in the case of Valle del Cauca, the visions of the departments of Sucre, Córdoba and Bolívar in the Colombian Caribbean region coincide with a vision of bioresources with the elements of bioecology. In general, they visualize themselves as agro-industrial departments with prioritized value chains, including the importance of biodiversity conservation, soil and ecosystem restoration, and efficient water use. They also stress the importance of food security and improving the quality of life of the population.

2.2 Colombia's strategy on bioeconomy

Drawing on the engagement exercises and analyses conducted at subnational level, along with reviews and discussions focused on national level, this section summarizes the key institutions and policies for Colombia and connects them to the bioeconomy roadmap.

Policies and institutions

Policies and initiatives like the Green Growth Policy (DNP, 2018) and the International Mission of Wises in 2019 (Gobierno de Colombia, 2019) were important drivers to develop the bioeconomy. Although they did not focus on bioeconomy, they highlighted the importance of promoting new ways of doing business based on biomass and biodiversity, giving nature a central role in the economy and paving the way for the first bioeconomy policies. Then, in 2020, led by the Ministry of Science, Technology,

and Innovation in collaboration with the National Planning Department, the formal and structured leading strategy Bioeconomy Mission of 2020 was finally launched (Gobierno de Colombia, 2020).

The Bioeconomy Mission of 2020 proposed the definition of bioeconomy in Colombia as well as objectives and a 10-year roadmap, paving the way for subsequent policies and providing a general framework for the bioeconomy development in the country. The proposed concept of bioeconomy aligns with the definition given by Global Bioeconomy Summit (2018), and is localized with the definition given by the Green Growth Policy. Compared to Global Bioeconomy Summit's definition, the concept of bioeconomy in Colombia emphasizes biodiversity and biomass as the biological resources to manage.

> *"An economy that efficiently and sustainably manages biodiversity and biomass to generate new value-added products and processes, based on knowledge and innovation."*
>
> Gobierno de Colombia, 2020

The Bioeconomy Mission of 2020 prioritized five key sectors: (1) biodiversity and ecosystem services; (2) bio-intelligence from biodiversity; (3) sustainable and productive agriculture; (4) biochemistry; and (5) health and wellbeing. It also identified two important and transversal themes to support the development of bioeconomy in these sectors: governance and regionalization, and incentives and investment.

Several key policies have been promoting bioeconomy as a path to achieve sustainability. The Development National Plan for 2022–2026 (Gobierno de Colombia, 2023), also known as "Colombia, life's world power", constitutes the government's development roadmap, setting its priorities and key policy objectives for the next four years. Bioeconomy is seen as a channel to achieve the key policy objectives of "Human Right to Food", and "Productive Transformation, Internationalization and Climate Action", making bioeconomy one of the spearheads for Colombia's sustainable development. Another key policy related to bioeconomy is the National Reindustrialization Policy (DNP, 2023). Its main objective is to leverage "added value in the production of goods and services" to facilitate economy transition from dependence on extractive activities to a productive, sustainable, inclusive and knowledge-based economy. The four sectors prioritized in the National Reindustrialization Policy are:

1. Just energy transition;
2. Agro-industrialization and food sovereignty;
3. Reindustrialization in the health sector; and
4. Reindustrialization for defence and life.

The bioeconomy is set to be one of the main drivers to promote agro-industrialization and food sovereignty and to contribute to a just energy transition and reindustrialization in the health sector, mainly through biomass utilization and phytomedicines, respectively. Moreover, the new government of Gustavo Petro (2022–2026) reviewed the previously published Bioeconomy Mission of 2020 and promoted a different methodology to complement it, focusing more on the different subregions

within the country, through a collaborative co-creation with the communities and with a more comprehensive monitoring and evaluating processes.

The roadmap

In 2023, a complete and detailed new 10-year roadmap to implement the bioeconomy in Colombia was published by the new government of Gustavo Petro within the Mission of Bioeconomy and Territory policy (Minciencias, 2023). This policy identified the main challenges to implement the bioeconomy, defined the national vision, and stated a general objective and specific objectives to achieve the vision, thus redefining the Colombian Bioeconomy Strategy.

This roadmap was built as an update of the Bioeconomy Mission of 2020 (Gobierno de Colombia, 2020). The new roadmap was much more inclusive due to several workshops with local leaders and communities which allowed it to recognize, make visible and use as input the differences among regions, establishing priorities for each one. Thus, it recognized differences among ecosystems and therefore the products it can offer, as well as the diversity of communities and their knowledge of the territory. It also established a clear and comprehensive set of indicators for monitoring and evaluating each objective of the roadmap implementation, bearing in mind methodological considerations for proper monitoring.

A key bottleneck identified for bioeconomy strategy implementation was the low level of development (e.g. fragmented, low level of transformation, little access to markets) of value chains based on the sustainable use of biodiversity and biomass in the regions of Colombia. Therefore, the concrete challenges for advancing the bioeconomy are how to:

- Make use of accumulated knowledge on biodiversity and ecosystem services, recognizing the intrinsic value of biodiversity and its essential role in ecological and social sustainability;
- Develop value chains without compromising protection and responsible use of biodiversity; and
- Provide consistency and coherence in relevant policy frameworks and regulatory actions.

The articulation of value chains for sustainable use of biodiversity and biomass and the policy coherence needed to promote new markets will require some differentiation of actions across different priority sectors, as developed and explained in section 2.3.

2.3. Bioeconomy visions at the national level in Colombia and sustainability challenges

To define the country's vision for the Mission of Bioeconomy and Territory (Minciencias, 2023), workshops with experts, businesses and communities were performed. The vision is stated as:

> *"By 2033, the Bioeconomy will contribute to the sustainability of the Colombian economy, based on the strengthening of value chains for the generation of bio-based products and services in a strengthened knowledge society and aimed at increasing the productivity/competitiveness of the regions to national and international level."*
>
> Minciencias, 2023

To comply with this vision, stakeholder views on goals, indicators, sustainability and inclusivity were considered in more detail, as outlined below.

Characterization based on stakeholder views

Based on the five sectors prioritized in the Bioeconomy Mission of 2020 and by synthesizing views from stakeholders, the vision for bioeconomy in Colombia was detailed by prioritizing eight applications: 1) functional foods and drinks; 2) cosmeceuticals and natural cosmetics; 3) phytomedicines; 4) agricultural bio inputs; 5) bioremediation; 6) biopolymers; 7) biorefineries; and 8) science, technology and innovation applied to nature tourism.

To support these different aspects or sectors, four overarching goals were developed, each of which has several metrics and indicators designed to evaluate and monitor implementation progress, as shown in Table 4.

Table 4. Specific goals for achieving bioeconomy vision and their corresponding indicators.

Specific goals	Indicators
Increase science, technology and innovation capacities at the national level to develop bio-based products and services.	Transfer rate of patents granted at the national level in the applications prioritized in the mission
	Number of research groups working on applications prioritized by the mission
	Number of postdoctoral stays carried out by the applications prioritized by the mission
	Employability rate of doctors in applications prioritized by the mission
	Number of mechanisms offered by the ministry for the financing of programs or projects related to prioritized applications
Strengthen the articulation between the actors involved in the different links of the value chains for generating bio-based products or services.	Number of actors (e.g., communities, academia, productive sector, government actors) involved in the development of projects related to prioritized applications
	Number of companies involved in links in the value chain of prioritized applications
Increase the sophistication, positioning and diversification of the national market for bio-based products and services.	Number of bio-based products and services at the national level related to the applications prioritized by the Bioeconomy and Territory Mission
	Number of spin-offs and startups related to the applications prioritized by the Bioeconomy and Territory Mission/total spin-offs and startups in the country
	Number of business development programs and instruments that leverage the bioeconomy
Increase the country's competitiveness to enter international markets with high added value.	Number of incubators or accelerators of bio-based companies

Source: Minciencias (2023).

Sustainability and inclusivity

To ensure that bioeconomy visions are sustainable and inclusive (Canales & Gómez, 2020), four main challenges were identified for the implementation of a national bioeconomy policy in Colombia.

1. Balancing use and conservation of biodiversity: Actions are needed to effectively conserve Colombia's biodiversity and preserve natural capital but also to balance with sustainable use of biodiversity for development goals (SDGs 14 and 15).
2. Ensuring effective sustainability standards: Results must be properly monitored to ensure that sustainability standards are functioning as intended.
3. Employment competition in new industry vs traditional agriculture: Expansion of precision agriculture may lead to job displacement within the agricultural sector, raising concerns about the absorption of these displaced workers into other employment opportunities.
4. Facilitating rural development: For equitable access to the bioeconomy, it is necessary to resolve challenges such as property rights in land ownership (currently, 60% of the land lacks property rights (Semana Rural, 2019)), and road infrastructure (75% of tertiary roads are in poor condition (Departamento Nacional de Planeación, 2019)).

Meeting these challenges also requires clear identification of impacts from rural development on land use and resources to avoid land degradation, deforestation and negative effects on soil or water.

As there are many challenges, Canales & Gómez (2020) highlighted key action points to develop the bioeconomy at a national level. These were divided into sectoral groups for agriculture, biochemistry, biopharmaceuticals and bioenergy, which are strategic sectors for Colombia’s bioeconomy. The formulated actions are summarized in Table 5.

An inclusive and effective national policy will consider the diverse visions and physical characteristics of the different regions of the country. The recently published Mission of Bioeconomy and Territory policy (Minciencias, 2023) recognizes these ecosystem and territorial differences, and is nourished by the different visions to highlight each region's potential in implementing the bioeconomy:

“Colombia’s bioeconomy policy establishes a territorial approach that recognizes Colombia's diversity and seeks to adapt bioeconomy strategies to the specific capacities and needs of each territory; thus, promoting equitable and sustainable development that generates substantial benefits. This approach, for example, ensures the acceptance of bioeconomy projects by local communities in their early stages providing benefits to all members and guaranteeing that projects are sustainable in the long term.” (J. Regino, Ministry of Science, Technology and Innovation of Colombia, 2024).

Table 5. Actions to be implemented to promote sustainable and inclusive bioeconomy in Colombia.

	Agriculture group	Biochemistry group	Biopharmaceuticals group	Bioenergy group
Governance	• Integrate the bioeconomy into strategic science and technology planning. • Include the bioeconomy in strategic sectoral planning. • Ensure policy coordination at territorial level. • Understand socio-ecological conflicts within territories.	• Formalize circular economy businesses. • Align bioeconomy priorities to regional competitiveness agendas.	• Prioritize phytopharmaceuticals. • Prioritization of bioresources for the bioeconomy. • Ensure Ministry of Health works together with Ministry of Agriculture to integrate agriculture into high-value-added production.	• - Prioritize biomass supplier sectors. • - Provide state leadership on promoting bioenergy generation on large and small scale.
Strengthen capacities & facilitate technology transfer	• Ensure access to information on agricultural potential of bioeconomy. • Establish good agricultural practices (e.g. precision agriculture and bio inputs). • Locate processing in primary production areas. • Encourage wide use of residual biomass in primary production areas.	• Ensure access to information on value chains for biochemistry uses and applications. • Create information system on residual biomass and by-products. • Provide technical assistance for residual biomass management. • Create regional technology clusters.	• Create information system on uses and applications of bioresources in phytopharmaceuticals. • Establish good manufacturing practices. • Ensure infrastructure for collection and processing plants in territories.	• Ensure technology transfer and technical assistance in circular economy. • Establish good practices for the sector. • Ensure infrastructure for waste biomass collection and processing plants.
Leverage economic resources		• Reduce capital costs for startups. • Provide credits for R&D+I in processing. • Provide benefits to companies including local actors.	• Provide subsidies to develop priority value webs (similar to those for flowers and banana growing). • Provide royalties for public sector investment in phytopharmaceutical research.	• Reduce capital costs (e.g. machinery import taxes). • Incentivize bioenergy production with a bioenergy bonus. • Engage fintech for the establishment of a fund capitalized by stakeholders.
Environmental and social sustainability	• Maintain road infrastructure to mobilize biomass. • Resolve land ownership issues. • Assess impact of bioeconomy on climate change and land use change. • Include Indigenous knowledge and cultural identity.	• Maintain road infrastructure to mobilize biomass. • Create environmental labelling for bioproducts. • Provide infrastructure for technology, information and communication (for information flows).	• Maintain road infrastructure to mobilize biomass. • Align to international sustainability standards.	• Create sustainability criteria, including impact on ecosystems and other resources. • Maintain road infrastructure to mobilize biomass. • Ensure regeneration of biomass and genetic material.

Source: (Canales & Gómez, 2020).

2.4 Bioeconomy strategy implementation in Colombia

The implementation of the Colombian Bioeconomy Strategy, defined in the Mission of Bioeconomy and Territory policy (Minciencias, 2023), must consider the challenges posed by the plurality of ecosystems, communities and customs and different levels of capacities, abilities and infrastructure across the country. This section presents the enabling actions for implementing the bioeconomy strategy in Colombia and critically reviews the main constraints related to it.

Enabling actions

Three main types of enabling actions are identified: formalizing supply chains; identifying and promoting technological advances; and arranging financing. The two main government ministries involved are the Ministry of Agriculture and the Ministry of Science, Technology and Innovation.

The Ministry of Agriculture promotes supply chain formalization for crops such as rice, coffee, cacao, banana and sugar cane. Legal representation is established to have a voice and connection with the government. Furthermore, this action serves as a platform to link to the private sector and establish standards and indicators for performance, policies and monitoring (MADR, 2015). In addition, these bodies use similar institutional structures to develop supply chain competitiveness and sustainability agreements. The agreements are found for coffee (MADS & MADR, 2021), cocoa (MADS, 2018), milk (MADS, 2019b), beef (MADS, 2019a), palm oil (MADS, 2017), and forest products (MADR, 2011).

To promote technological advances and spread the current technology available, the government has created subnational committees, called Departmental Councils for Science, Technology and Innovation (Minciencias, 2017), to engage multiple stakeholders, including public, private and academic actors. These committees aim to communicate enterprise needs in technology advancement to the academic units. Furthermore, the committees identify the differing needs of different territories and promote research and innovation to find solutions for them.

To finance implementation of the bioeconomy, the Ministry of Science, Technology and Innovation launched several calls offering grants to promote research, technological development and innovation based on alliances among private sector, public sector and academia, such as Call #43 with a budget of USD 47 million (Ministry of Science and Technology of Colombia, 2024a) and Call #956 with a budget of USD 2.3 million (Ministry of Science and Technology of Colombia, 2024b). Nevertheless, more financial schemes and sources are needed:

> *"Developing financing systems that promote private investment in bioeconomy projects from the earliest stages of research to the commercialization stage is also key. This includes creating risk-sharing funds, tax incentives for bioeconomy R&D and innovation, and credit systems with favourable conditions for startups and companies that develop innovative bioproducts. These mechanisms should be designed to reduce financial risk and stimulate investment in projects that may have a longer and riskier development cycle, characteristic of the bioeconomy."*
>
> J. Regino, Ministry of Science, Technology and Innovation of Colombia, 2024

Constraints

As the implementation has faced multiple challenges, several constraints have been identified for boosting the bioeconomy in Colombia. These constraints were identified at three scales: policies and institutions, business models, and technology.

One policy constraint is the complexity of laws and regulations, which discourages sustainable use of forest resources. For example, policies regarding the use of wildlife for commercial purposes require complex regulatory processes to get certification. This can end up blocking bioeconomy products from reaching the commercialization stage (ICA, 2004, 2015).

> *"For the successful functioning of biotechnology-based companies in Colombia, it is essential to adapt existing regulations to the origin of bioproducts, highlighting their low-risk level due to advanced technological development and scientific studies. The involved state entities must have clear responsibilities, defined processes, and trained personnel to evaluate these products."*
>
> A. Herrera, General Manager of Bichópolis-Biobee Colombia, 2024

Furthermore, the Bioeconomy Mission's 2020 strategy posed several constraints to policy development for its implementation. First, the proposed vision is too general without considering the characteristics of each region in the country; in this way, it constrains adaptation to the specific conditions of the territory. Second, indicators to measure the performance of the strategy are absent (at an economic, social and environmental level), which hinders monitoring and evaluation of the impacts and results of the implementation. These issues were addressed by the Mission of Bioeconomy and Territory (Minciencias, 2023).

Regarding business models, although some bioresources have legally constituted supply chains, they still lack comprehensive monitoring of indicators and product traceability. Meanwhile, some bioresources do not yet have formalized supply chains, while others may not yet have completed sustainability agreements.

Currently, most of the bioproducts are obtained in small-scale businesses or are obtained by wild harvesting, so it remains challenging to cope with increasing market demand, making bioproducts mainly a niche type of product. In addition, there is a need to apply for quality certifications (such as seed health, good manufacturing practices or food safety) which results in a bottleneck to promoting products in several markets where certifications are needed.

In parallel, the current lack of labour and generational change in bioeconomy industry poses a constraint. Mechanization is not common yet, and most young people in rural areas are migrating to urban areas and it is increasingly challenging to find enough workers to harvest crops. In parallel, most farmers demand a more equitable distribution of benefits and fairer prices, as most of the earnings are concentrated in the commercialization step and small and medium-scale farmers often have less negotiation power.

The stakeholders remarked that research and innovation centres are not involved with industry and other sectors, and entrepreneurs particularly highlighted the high-profit percentages that academies demand as well as the bureaucratic processes, permits and restrictions to develop bioproducts, all discouraging cooperation between academia and enterprises.

From a technological perspective, high transportation costs and a lack of basic services in the regions, such as water and energy, are blocking the transformation of raw materials. In addition, there is not enough infrastructure or installed capacity to produce and meet the needs of the market. Moreover, there is a lack of research on the machinery needed to process the raw materials so most of the machines are imported, creating a barrier entry for small and medium-scale producers.

Finally, as a high percentage of bioproducts are related to crops, another set of barriers or constraints arises from lack of seed production and distribution programs, use and management protocols, and specialized knowledge in crops at the national level.

2.5 SWOT analysis of bioeconomy in Colombia

Colombia's biodiversity and local and traditional knowledge regarding nature constitutes a huge potential to promote the bioeconomy as a driver for sustainable development, as the government has established it through the Mission of Bioeconomy and Territory (Minciencias, 2023). Nevertheless, there are also significant challenges that encompass the entire chain from resources to final products and services. The analysis in this section, including the enablers and constraints, is synthesized in the SWOT analysis shown in Table 6.

Table 6. SWOT analysis of Colombian bioeconomy

Strengths	Opportunities
• Rich biodiversity and abundant natural resources provide substantial raw materials for bio-based industries. • There is strong political commitment and support for the development and implementation of bioeconomy. • Ongoing national bioeconomy programs facilitate continuous improvement and adaptation of bioeconomy.	• Bioeconomy initiatives generate employment across various sectors. • Substantial quantities of organic residues are available for upcycling. • The bioeconomy can be leveraged as a strategic advantage for tropical regions and to “tropicalize” the bioeconomy. • Social diversity and multiple communities can provide traditional knowledge regarding biodiversity and its uses (e.g. medicinal plants, nutritional fruits and vegetables).
Weaknesses	**Threats**
• Lack of connection to market supply chains hinders the development of the bioeconomy, limiting the commercialization and scaling of bio-based products and innovations. • Insufficient infrastructure and communication networks in Colombia limit the efficient transport, processing and commercialization of bio-based products. • There are still conflicts around land ownership, and in some subregions it is not completely clear and is not enforced by local authorities. • The absence of economic, social and environmental indicators hinders effective monitoring and policy formulation, impeding the assessment and targeted improvement of outcomes in the bioeconomy sector. • Absence of business models for agricultural products and their value chains. • The shortage of specialized skills around the process to obtain bioproducts within the bioeconomy. • Poorly diversified economies with low value addition. • Social inequality and poverty.	• Climate change-related events, such as droughts, floods and pest outbreaks, could disrupt agricultural production and supply chains, impacting the reliability of bioeconomy feedstocks as raw materials for bioproducts. • ·The potential loss of biodiversity, resulting in reduction of the availability of diverse bioresources, undermines the bioeconomy development. • Precision agriculture's expansion may conflict with traditional agricultural jobs due to its emphasis on automation and efficiency through technology. • There is a lack of available labour in the rural areas due to a generational change where young people are migrating to urban areas.

Sources: authors’ analysis

3. Thailand’s national bioeconomy strategy and implementation

Thailand has positioned itself as a regional leader in Southeast Asia's bioeconomy, capitalizing on its biodiversity and robust agricultural sector. The country has embedded bioeconomy principles into its national development strategies to foster sustainable economic expansion. Emphasizing sectors such as agriculture, forestry, healthcare and energy, Thailand seeks to optimize the sustainable utilization of biological resources. This strategic initiative not only aims to spur economic growth but also addresses environmental imperatives while enhancing the livelihoods of rural communities. By integrating bioeconomy initiatives, Thailand aims to cultivate a more sustainable and inclusive economy, balancing economic advancement with environmental stewardship. The effectiveness of Thailand’s bioeconomy strategy, national vision, and implementation framework are outlined in this section, which concludes with a SWOT analysis.

3.1 Thailand's strategy on bioeconomy

The Thai government has aimed to create a supportive environment for the bioeconomy in terms of the national development strategy, adjusting regulations and providing financial support alongside various efforts for enhancing inclusivity and social equity. The Bio-Circular-Green (BCG) framework established the bioeconomy as a key dimension of the national development agenda in relation to the Thailand 4.0 industrial policy launched in 2017 (Ministry of Industry, 2017). The policies, institutions and roadmap are outlined and assessed below.

Policies and institutions

The Thai approach to bioeconomy has prioritized key relevant sectors, including agriculture, forestry, healthcare, energy and ecotourism, with particular emphasis on agriculture. Meanwhile, Thailand supports the private sector in bioeconomy development through subsidies to accelerate the adoption and expansion of new agro-industries in order to make it competitive in a global market. On the finance side, the government has deemed investments within bioeconomy as "privileged", launching 0% import tax on foreign equipment and up to eight years of corporate income tax exemption, plus an additional 50% reduction for five years (Changsorn, 2017). Additionally, the government has already invested significantly in R&D; for example, the National Biotechnology Framework for 2012–2021 describes increased support to develop human capacity within the biotechnology field through the Human Resource Development Program (Ministry of Science and Technology, 2012).

The Twelfth National Development Plan (2017–2021) identified income equality, access to justice, and access to public services as some of the pressing concerns related to inequality. Its specific aims are reducing poverty, enhancing land ownership opportunities for the landless, and boosting communities' economic independence (Thailand National Economic and Social Development Board, 2017).

> *One of the key strategies to strengthen the coordination between government agencies and private sector is through adjusting the government spending mechanism from short-term solutions to investment in research and development of technology that leads to sustainable solutions or lead to economic restructuring that extends agricultural output to high-value biological products.*
>
> — BIOTEC (SEI, personal communication, 2023a)

> *The BCG Economic Model is a new driving mechanism for the country's economic growth. "Quality Growth" Create a balance between a value-based economy, inclusive growth, and a circular society that uses resources wisely to increase resources.*
>
> — BIOTEC (SEI, personal communication, 2023a)

Policy support for both large and small-scale bioeconomy products faces two crucial challenges. The first is the lack of coordination between commercial and conservation aspects in cross-sectoral policymaking within inter-ministerial arrangements. The second challenge is the need for tailored regulatory approval and incentives for different types of actors and production scales. For example, large-scale crops raise concerns about pricing, supply chain management, and sustainability. Meanwhile, small-scale crops or bioresources require regulatory support to access raw materials and market biodiversity-based products sustainably and safely. Addressing these issues through more integrated and tailored policies is essential for the holistic development of the bioeconomy.

The ultimate goal for bioeconomy-related policies is to help Thailand achieve a higher income status using the natural resources as competitive advantage through science, technology and innovation with the responsibility to utilize the resources in a sustainable manner (Fielding & Aung, 2018). Moreover, bioeconomy was featured both in the “short to medium term” and “long term” plans to develop key industries under the Thai government’s phased economic development plan, Thailand 4.0. There are several reasons that bioeconomy underpins economic growth and development in Thailand:

- Thailand has a high-level of infrastructure development which serves as an added value development linked to the knowledge-based bioeconomy.
- Thailand has abundant sources of raw materials with great potential for bioeconomy-related development, especially in key agriculture sectors (e.g. rice, cassava and sugar cane; Lakapunrat & Thapa, 2017).
- The Government of Thailand’s vision of bioeconomy for the country rests on a plan to modernize agriculture through value-added products and services. Although this plan supports Thailand in overcoming middle-income status, it is unable to generate enough further income to reach upper-income status (Oxford Business Group, 2018).

To promote the development of industrial bioeconomy, Thailand invests in R&D of biotechnology for energy, agriculture, chemical and pharmaceutical industries. It also offers a wide range of tax and non-tax incentives, particularly to cassava and sugar cane sectors for producing value-added products such as biofuel, bioplastic and bio-additives (Thai Ministry of Industry, 2018).

The roadmap

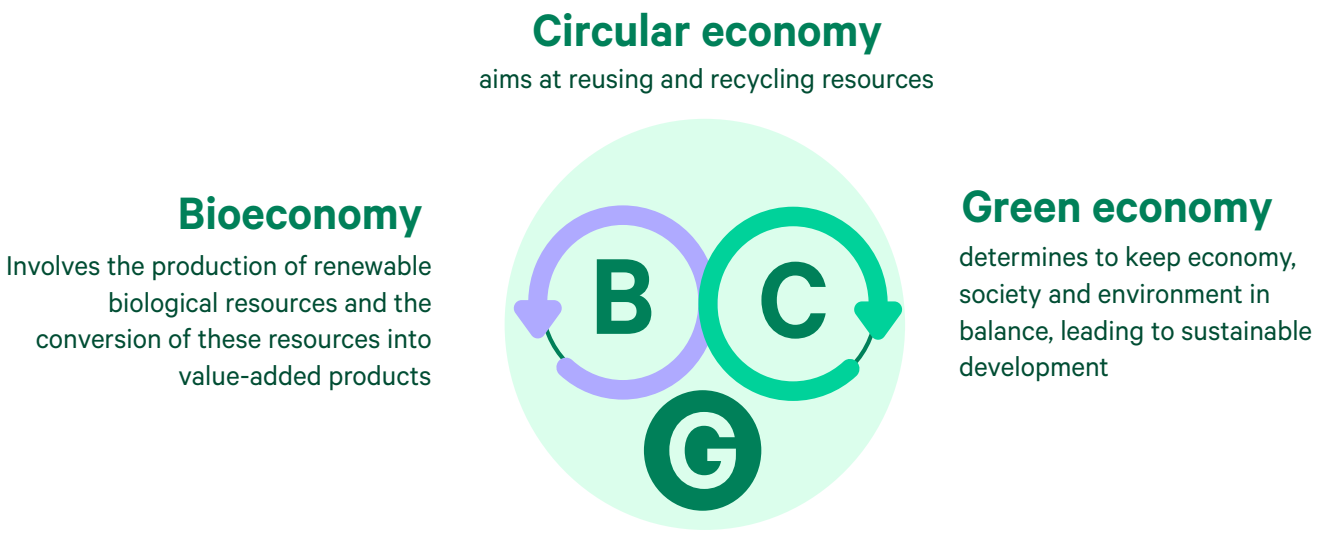
As discussed in the introductory section 3.1, the BCG economy, illustrated in Figure 1, was presented as a key element of the Thailand 4.0 industrial policy launched between 2017 and 2019. Under the BCG model, there are four sectoral developments prioritized by the government:

> *Currently, many measures have already been implemented, such as increasing investment incentives, amending urban planning, and improving regulations to allow sugar cane juice to be used to produce products other than sugar. This has led to investment in the bio-industry in the upstream sector.*
>
> — Bio-Agriculture and Non-Food Industry Group, Office of Industrial Economics (SEI, personal communication, 2024)

1. food and agriculture;
2. medical and wellness;
3. energy, material and biochemical; and
4. tourism and creative economy.

It is expected that the BCG model will not only address the "middle-income trap", but also contribute to achievement of SDGs. The Thai government has issued various roadmaps for different components that relate to the BCG such as bioplastic and biopharmaceuticals (BOI, 2017). However, there is not one single unified roadmap for bioeconomy.

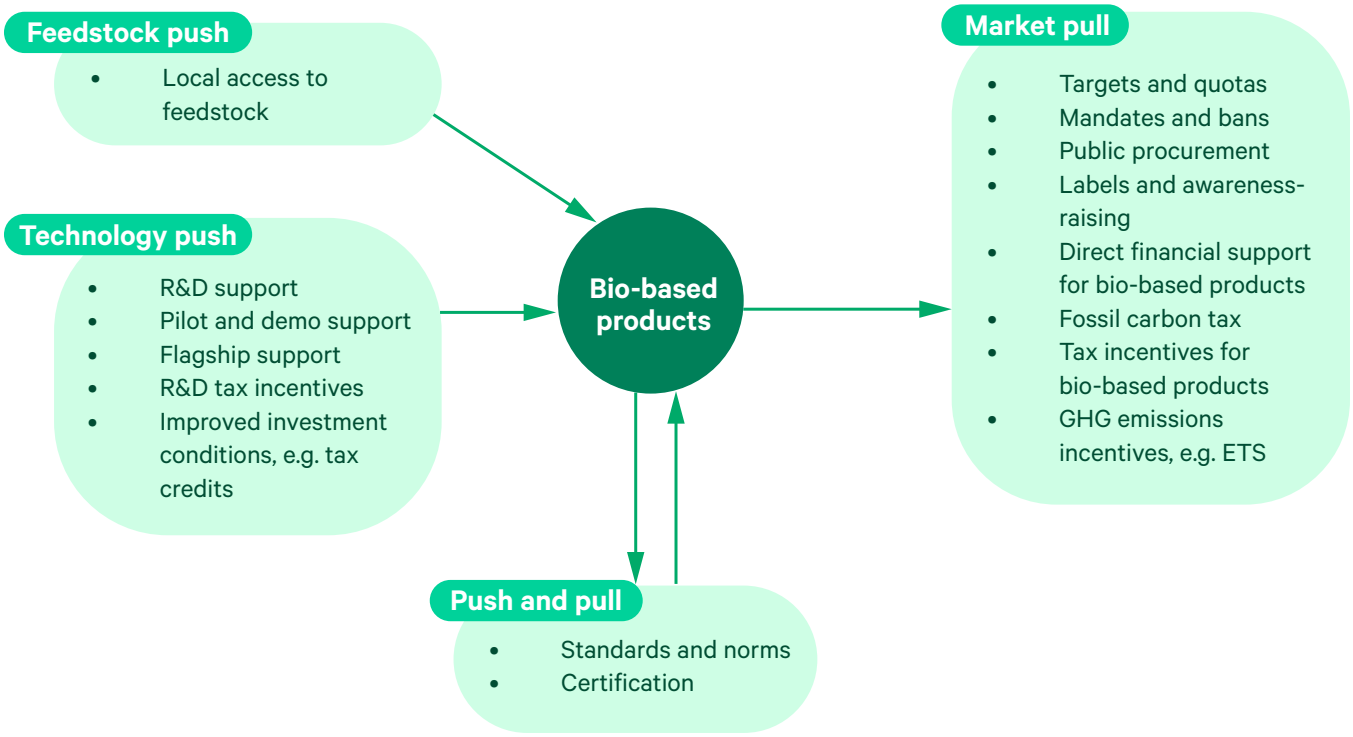
Figure 1. BCG model in Thailand.



Source: (NSTDA, 2020)

The OECD recommends that the Thai government better clarify the specific goals of the bioeconomy strategy (OECD, 2013). The government has to decide how to prioritize key aims, including ensuring farmers' welfare, reducing inequality, promoting sustainable agriculture, and enhancing climate change adaptation. Since one strategy cannot address all these goals, the OECD recommends development of a roadmap for the bioeconomy strategy to be created with specific, targeted focus areas. The OECD recommendations also outlined different policy measures that could promote the implementation of bioeconomy as seen in Figure 2.

Figure 2. Bioeconomy policy measures in Thailand.



Note: GHG = greenhouse gas; ETS = emissions trading system

Source: (OECD, 2021)

A unified bioeconomy roadmap would require strong coordination among policymakers across different domains, including research, innovation, agriculture, economy and environment. This cross-collaboration and inter-ministerial cooperation in turn requires adequate budget, formation of expert groups, information exchange, and participatory decision-making processes. Although it is logical to have a unified roadmap, it should be noted that the OECD recommendations are not necessarily catered for the particular circumstances in Thailand.

3.2 Bioeconomy visions at the national level in Thailand and sustainability challenges

Thailand has gone through different stages in its development planning, starting before 1960 when the economy was focused on agriculture in a phase referred to as Thailand 1.0. This was followed by the light industry phase, known as Thailand 2.0, followed by more advanced industries after 1987 with Thailand 3.0. However, this led to the "middle-income trap" of rising inequality. The aforementioned latest phase as of 2017, Thailand 4.0, focuses on innovation, knowledge, technology and creativity featuring the "Bio-Circular-Green Action: The New Sustainable Growth Engine" with bioeconomy as a key focus (NSTDA, 2020). This focus is incorporated into the 20-year National Strategy (National Strategy Secretariat Office, 2018).

The 20-year National Strategy encapsulates different elements of all three visions of bioeconomy as studied by Bugge et al. (2016). The Strategy explicitly states that the development of the bioeconomy will “lead to quality-of-life enhancement, social fairness improvement, environmental risks reduction, and reduce environmental scarcity; people will enjoy a higher quality of life, with less negative impacts on environment” (National Strategy Secretariat Office, 2018). In addition to these policies, Thailand’s bioeconomy is also rooted in The Sufficiency Economy Philosophy promoted by the Late King Bhumibol Adulyadej, which encourages “moderation, reasonableness, and resilience”, aligning with the bioeconomy’s goals of efficient resource use (Thailand National Economic and Social Development Board, 2017).

Stakeholder analysis

Despite much of the economy already being bio-based, the artisanal or smaller-scale bioeconomy has not been a major focus. An implementation gap exists between industrial bioeconomy and artisanal bioeconomy in terms of opportunities, finance, infrastructure, innovation and market access. The Biodiversity-based Economic Development Office (BEDO) was established in 2007 with the mission to narrow this gap by building an economy that utilizes biodiversity and innovation to conserve as well as generate profit for local communities. BEDO works with small and medium enterprises by promoting community participation in BCG models and fostering collaboration for the development of an inclusive, sustainable and community-driven bioeconomy.

> *There are three key elements that are important for Thailand’s bioeconomy strategies according to Dr Tanit Changtavorn from BEDO: Firstly, utilization and conservation. This utilization and conservation have to be hand in hand. We cannot promote the utilization without looking after the biodiversity, so that's why we have to look after our biodiversity by conservation program. Secondly, inclusiveness is very important because we don't want to leave anyone behind us so people in the rural area have to be looked after, that’s why BEDO work a lot to help people in rural area, especially in communities on community enterprises. Finally, sustainability is the final important key for the strategies. Everything that BEDO has done in order to promote bioeconomy, we have to achieve sustainability or sustainable development*
>
> — Biodiversity-based Economy Development Office (BEDO) (SEI, personal communication, 2023b)

The Thai bioeconomy stakeholders can be characterized into four main categories (Aung et al., 2020b):

1. **Agenda setters:** Thailand's bioeconomy places a strong emphasis on industrial bioeconomy, with the private and industry sectors playing a crucial role as key agenda setters. These key stakeholders are actively involved in policy decisions through working groups as part of a Public-Private Partnership (PPP) scheme to advance the bioeconomy. On the government side, the Office of Industrial Economics and the Office of Cane and Sugar Board (OCSB, 2019), both under the Ministry of Industry, also contribute to setting policy agendas.

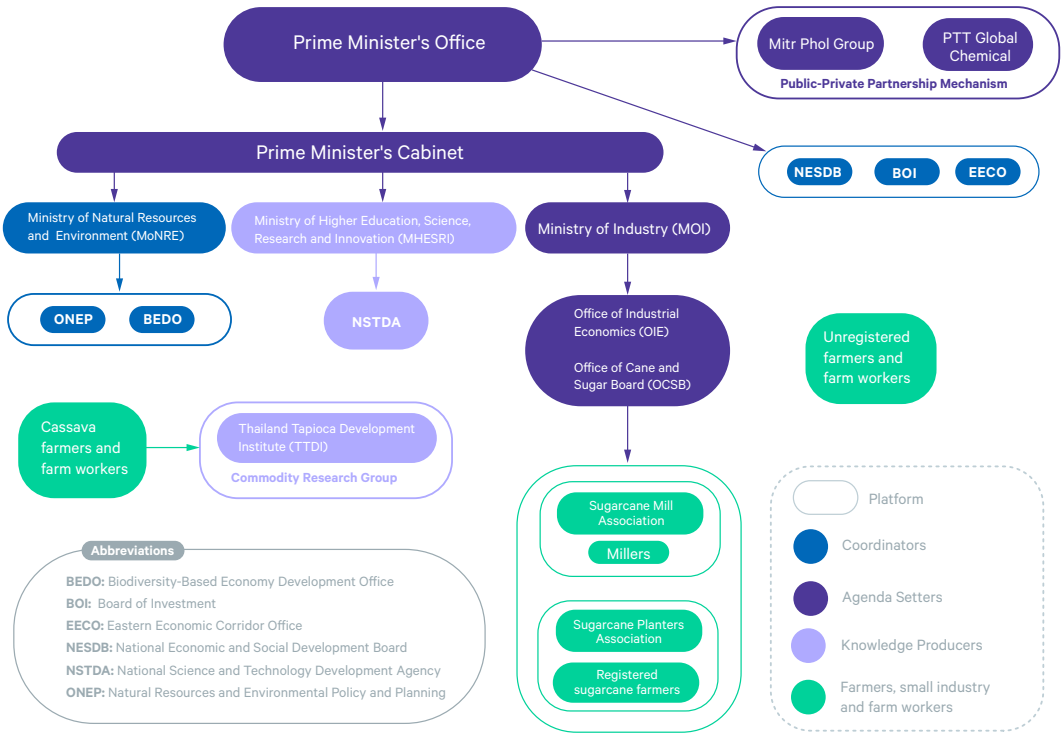
2. **Coordinators:** The Prime Minister's Office serves as the central coordinator for the bioeconomy, working through various boards and agencies. This includes: the Eastern Economic Corridor Office (EECO), which drafts the bioeconomy master plan and strategies; National Economic and Social Development Board (NESDB), which develops national economic and social development strategy; and the Board of Investment, which offers incentives such as tax breaks to encourage investment in the bioeconomy. The NESDB acts as a coordinating body, although its mandate extends beyond just the bioeconomy. The Ministry of Natural Resources and Environment, through Natural Resources and Environmental Policy Planning (ONEP), is tasked with reviewing the environmental impact assessments of bioeconomy-related projects. Additionally, as mentioned earlier, BEDO plays a crucial role in supporting communities and small-medium enterprises within the bioeconomy sector.

3. **Knowledge producers:** The Ministry of Higher Education, Science, Research, and Innovation (MHESRI/NXPO) plays a crucial role in advising on policy implementation for Thailand's bioeconomy strategy, which focuses on science, technology and innovation. The ministry analyses regulatory frameworks and conducts research to advance the strategy, including ensuring sustainability standards across various industries. In addition, the National Science and Technology Development Agency (NSTDA) provides R&D funds and conducts technical research on bioeconomy (NSTDA, 2019).

4. **Farmer's groups:** Farmers and workers, particularly smallholder farmers, lack influence and resources in the current bioeconomy model despite their crucial role in the value chain and strategy implementation. Their involvement varies widely, and many are marginalized due to factors such as social and economic status, land ownership, legal status, nationality and gender. Smallholder farmers risk being in a disadvantaged position regarding their contractual terms and cost-benefit sharing within the private sector, while non-energy crop growers and local communities may worry about water pollution from excessive chemical use. Additionally, non-Thai migrants and women farmers and workers face challenges such as limited access to social services and unequal pay.

Figure 3 shows the relationship among different stakeholders, emphasizing organizations and institutions associated with the two key agricultural bioresources for bioeconomy development in Thailand – cassava and sugar cane.

Figure 3. Stakeholder mapping of Thai bioeconomy.



Source: adapted from Aung et al. (2020a)

Sustainability and inclusivity

There are opportunities in Thailand to adjust the implementation of the bioeconomy strategy to include key socio-economic objectives. Thai visions for bioeconomy explicitly include the need to reduce inequality and address poverty (Aung, 2021), distinguishing it from numerous other national strategies and stakeholder tendencies in which visions of the bioeconomy are weighted more heavily towards ecological and economic/resource outcomes (Bugge et al., 2016).

This tendency to ignore or only minimally include social aspects is common in many countries, and it has led to a push for a “socio-bioeconomy” that aims to empower local communities and Indigenous Peoples by orienting bioeconomy strategies in a more balanced way that recognizes the unique features around their stewardship of bio-based resources (Johnson & Zhu, 2024). To establish the socio-bioeconomy, it is crucial to encourage collaboration among key policymakers, small-scale businesses of farmers and workers, research institutes, NGOs and civil society actors. Inclusive, collaborative, evidence-based decision-making would encourage a more equitable bioeconomy.

The current challenges in Thailand include effectively organizing smallholder farmers into larger groups like cooperatives and clearly transitioning them into formal small and medium-sized enterprises (SMEs) (Fielding & Aung, 2018). Despite these difficulties, the country has a strong tradition of supporting smallholder farmers, stemming from state protection programs in the 1960s and 1970s that relocated farmers to upland

areas to prevent takeovers by large foreign plantations. While these initiatives have preserved a significant smallholder farming sector, issues such as inequality persist. The government has promoted contract farming since the 1980s, providing farmers with access to technical knowledge, improved farming methods, and price stability. However, it also presents challenges such as limited negotiating power, reduced autonomy, and insufficient social welfare benefits for farmers.

This evidence highlights the dynamic nature of power relations among stakeholders. This analysis reveals gaps in achieving Thailand's vision of social sustainability. Regarding the distribution of income and resources, growers are primarily concerned with receiving a fair share of the revenue from the bioeconomy. To realize Thailand's vision of a just society, the issue of low incomes for both growers and workers must be addressed. Policy interventions could improve environmental and human security for smallholders, especially if the focus is on an artisanal bioeconomy. This approach would help create a more sustainable and equitable bioeconomy in Thailand.

Our success has to do with the fact that we do Ban Wang Somsa Community Enterprise product in full cycle. It is from upstream, midstream, and downstream. At the upstream, we grow the raw materials ourselves, with the support from provincial agriculture office. We have a valid production facility to ensure the quality of the product. Finally, we sell the products ourselves to ensure the community will earn income from this business.

– President of the Community Enterprise Group for the Development of Bio-Resource Products for the Ban Wang Somsa Community Economy (SEI, personal communication, 2023b)

3.3 Bioeconomy strategy implementation in Thailand

Enabling actions

As noted previously, Thailand has issued various supportive policies, legislation and capacity-building programs for the bieconomy. The PPPs embedded in the Thailand 4.0 policy hold a pivotal role in enabling the implementation of Thailand's bioeconomy and driving bioeconomy innovation, investment and infrastructure (Ministry of Industry, 2017). In these partnerships, the private sector takes the lead in setting development agendas, while the government offers crucial support in financial, regulatory and human capacity aspects (Fielding & Aung, 2018). Industry leaders serves as chairs of the private-sector committee within the multi-sector PPPs, which also have an executive committee (Kongkirati & Kanchoochat, 2018).

By providing opportunities for all sectors to participate, the measure has been accepted by all parties and has received cooperation in driving the measures to meet the goals of the measures continuously until now.

—Bio-Agriculture and Non-Food Industry Group, Office of Industrial Economics (SEI, personal communication, 2024)

Thematic working groups within these PPPs are also co-led by representatives from major corporations, including banks and other businesses, enhancing their effectiveness. Various initiatives have been launched to enhance collaboration between public institutions and private enterprises, focusing on R&D, fiscal support, SME

development, infrastructure enhancement, and technological innovation (Fielding & Aung, 2018). Other initiatives include the establishment of research groups and innovation hubs that bring together academia, industry and government agencies to work on bioeconomic projects.

Partnerships have also facilitated substantial investments in biotechnology and sustainable agriculture, with joint ventures and funding mechanisms supporting startups and small enterprises. Additionally, the development of shared infrastructure, such as biorefineries and research labs, has been a critical component of PPPs, providing access to cutting-edge technology and expertise, reducing entry barriers for smaller players in the bioeconomy. This comprehensive PPP scheme not only drives the development of the bioeconomy but also makes critical decisions and investments in bioeconomic infrastructure (Thai Community Development & Department, 2018). For instance, PPPs are instrumental in advancing infrastructure projects including transport, enabling airports, high-speed railways, and highways that connect economic hubs (Oxford Business Group, 2018). The institutional support system for the bioeconomy is structured in a top-down manner to ensure the sector's external competitiveness (Fielding & Aung, 2018).

To complement the top-down mechanisms of the PPPs, BEDO as a governmental agency actively engages in bottom-up efforts, playing a pivotal role in advancing the bioeconomy in Thailand at the grassroots level. BEDO has worked with local communities for almost two decades to improve community income and development, including major activities like Geographical Indication (GI) and community biobanks, ensuring that community voices are heard. BEDO provides financial support and in-kind assistance in connecting communities to funding sources and linking business opportunities. Additionally, BEDO facilitates connections between community enterprises and key agencies, like the Food and Drug Administration for product certification and the Small and Medium Enterprise Promotion Office (NSA) for enterprise growth support. Through these efforts, BEDO significantly enhances local community development and participation in Thailand's bioeconomy.

Constraints

Although social equity is stated as a goal in overall agricultural and industrial strategies, Thailand's implementation of the bioeconomy places a strong emphasis on industrial and economic perspectives, somewhat downplaying the environmental and social considerations. This is reflected in the influence of authorities – departments like BEDO, ONEP, and NESDB – which focus on environmental sustainability and community engagement but have limited influence on agenda setting and implementation (Mortensen, 2019). A notable example is in 2017 when the Prime Minister’s Office expedited environmental impact assessments for biotechnology projects in the EEC, overriding ONEP’s mandate by arguing these projects posed minimal environmental risks (Chiengku, 2019). Additionally, stakeholder engagement in the PPPs has also illustrated this issue, as non-industry-oriented government actors, NGOs, community groups, and small businesses are often excluded from the decision-making processes (EECO, 2018; Vongkusolkit, 2016).

This marginalization of socio-environmental factors, driven by a concentration of power among a few economic and political actors, has also led to significant socio-environmental challenges (Chiengku, 2019). This also results in the exclusion of smallholders, such as local farmers and the local artisanal bioeconomy, leaving them without supporting mechanisms (Fielding & Aung, 2018).

Additionally, contract farming arrangements, initially aimed at providing technical knowledge and price stability to farmers, have inadvertently limited their negotiating power and freedom. These arrangements often leave farmers without adequate social welfare benefits or safety nets (OECD, 2013; Tukaew et al., 2016). In 2018, to comply with World Trade Organization (WTO) regulations, the contract farming arrangements were revised to implement a floating sugar price mechanism. Theoretically, this change was meant to allow farmers more flexibility to negotiate prices. However, with the enactment of the floating sugar price, sugar prices have become subject to global market fluctuations. Without intervention, farmers' incomes are now impacted by price volatility, leading to financial instability.

Despite government efforts to engage with farmer networks, the top-down management approaching has often been misaligned with the community culture, resulting in limited success and making it difficult for farmers' concerns to affect decision-making. Meanwhile, farmers and workers remain the least influential stakeholders, facing diverse challenges such as contractual concerns, water pollution, and unequal access to social services (Fielding & Aung, 2018).

There are also negative environmental consequences resulting from social impacts. For example, labour shortages and costs are some of the main reasons that sugar cane farmers burn their sugar cane fields, as harvesting fresh cane is far more labour-intensive than harvesting burnt cane. This cane burning, however, results in air pollution and haze as well as lower biodiversity, soil erosion and exhaustion (Manivong & Bourgois, 2017).

> *The challenge in implementing the next phase of bioeconomy policy is to increase investment in the bio-industry to meet the set targets. Creating linkages and strengthening the domestic supply chain by creating more midstream and downstream bio-industries, and most importantly, strengthening technology to achieve sustainable development in the future.*
>
> — Bio-Agriculture and Non-Food Industry Group, Office of Industrial Economics (SEI, personal communication, 2024)

Overall, the current bioeconomy pathway underscores the need for greater inclusivity and balanced consideration of environmental, social and economic factors.

Synthesis of stakeholder views

In order to better understand what implementation actions were needed in relation to envisioned bioeconomy pathways, a stakeholder workshop was designed and carried out. Although most participants were Thai, several were invited from elsewhere in Southeast Asia in recognition of the increasing importance of regional approaches and strategies. The design was based in part on three bioeconomy visions: biotechnology,

bioresources and ecology (Bugge et al., 2016). The choice of breakout groups, however, also considered the interests and background of the participants: biotechnology remained the same, while agriculture was chosen instead of a bioresources group, and a group was chosen for socio-economic aspects instead of bioecological views (Gladkykh et al., 2020). The results from the discussion were synthesized and grouped into four key themes: 1) technology/infrastructure; 2) stakeholder engagement; 3) environmental and social sustainability; and 4) regional economy. In general, stakeholders emphasized technology and social inclusion in fairly equal proportion, while regional aspects were highlighted, which was due in part to Thailand's leadership in the region on bioeconomy (NSTDA, 2020). The results are provided in Table 7.

Table 7. Implementation actions for sustainable bioeconomy pathways, according to workshop participants

Themes	Stakeholder Group 1 (agriculture)	Stakeholder Group 2 (socio-economic aspects)	Stakeholder Group 3 (biotechnologies)
Technology and infrastructure	• Ensure energy and transport.	• Enable decentralized energy and transport. • Install a decentralized renewable energy-based electricity system.	• Cooperate with developed countries around technology, building domestic biotech capacity. • Build up regional technological capacity in Southeast Asia. • Enable production of sustainable bioproducts. • Activate market mechanisms to encourage the bioeconomy.
Stakeholder engagement and relations	• Set goals for bioeconomy, stakeholder participation and awareness raising. • Create functioning multi-stakeholder platform(s) for the bioeconomy. • Raise awareness about bioeconomy among general public and stakeholders. • Set clear bioeconomy objectives and goals. • Increase capacity for successful implementation of bioeconomy-related plans and strategies.	• Enable PPP initiatives and private sector participation. • Activate a stakeholders' bioeconomy platform. • Ensure inclusive stakeholder participation in bioeconomy decision-making processes.	• Enable PPP and bottom-up bioeconomy initiatives. • Ensure bioeconomy support from the public sector. • Create bottom-up activity related to bioeconomy initiatives. • Encourage PPP creation to assist bioeconomy activities. • Establish a communication platform for the production and consumption aspects of the bioeconomy.
Environmental and social sustainability	• Enhance crop/agricultural productivity, food security and farmers' well-being • Ensure agricultural/crop production are in line with safety standards. • Enhance efficiency of land and water use for agricultural production.	• Enable sustainable consumption, behaviour change • Enable sustainable practices of food and non-food products and services consumption, including service over ownership.	• Enhance farmers' economy and well-being.
Regional economic aspects	• Enable regional ASEAN cooperation on bioeconomy. • Share bioeconomy knowledge and experience at the regional level.	• Enable regional ASEAN cooperation on bioeconomy. • Ensure sustained political will on bioeconomy development at the country level and the regional level.	• Improve technology transfer and learning within the region.

Source: Gladkykh et al. (2020).

3.4 SWOT analysis of bioeconomy in Thailand

Thailand's bioeconomy boasts significant strengths and opportunities, stemming from its rich biodiversity and natural resources, such as sugar cane and cassava, and favourable climate conditions. PPPs play a crucial role in driving innovation, investment and infrastructure development in the country, supported by diverse regulatory frameworks and a national strategy focused on inclusivity and social equity. The tailored education system and capacity-building programs further prepare the workforce for bioeconomy advancements. The industry benefits from increased investments and a talented workforce, resulting in innovative bioproducts. Moreover, the rising global demand for bioproducts and employment opportunities across various bio-industries, including agriculture, forestry, healthcare, energy and ecotourism, enhances Thailand's bioeconomy. Collaborative efforts through global, regional and ASEAN partnerships facilitate knowledge transfer, technology exchange and market access, while private sector investments boost industry growth.

However, challenges exist, such as the industrial and economic bias that may overshadow environmental and social needs, and limited stakeholder engagement in PPPs from environmental and social sectors. Insufficient support mechanisms for artisanal bioeconomy and educational gaps in specialized training for smallholders further weaken the sector. Meanwhile, external threats include climate change-related events like droughts, floods and pest outbreaks that disrupt agricultural production and supply chains, impacting the reliability of bioeconomy feedstocks. The uncontrolled expansion of bioeconomy activities risks environmental degradation and biodiversity loss. Additionally, fluctuations in commodity prices, trade tariffs and market demand pose threats to the profitability and sustainability of Thailand's bio-based products. Market competition from countries with similar products and the price and technological advantage of conventional industries, such as fossil fuels, also challenge the adoption of bio-based alternatives. The SWOT analysis in Table 8 summarizes the issues for Thai bioeconomy development.

Table 8. SWOT analysis of Thai bioeconomy development

Strengths	Opportunities
• Rich biodiversity and natural resources as raw materials for bio-based industries, including sugar cane, cassava and favourable climate conditions • Leveraging PPPs driving innovation, investment, and infrastructure development with a top-down structure to ensure global competitiveness • Diverse regulatory support: setting national strategy, easing restrictions, providing financial aid, and considering inclusivity and social equity • Tailored education system and capacity-building programs to prepare workforce for bioeconomy development • Increased investments and talented workforces leading to more innovative products from bioeconomy industry	• Higher global demand for bioproducts, including existing and innovative ones • Employment opportunities in the identified bio-industries from value addition in agriculture, forestry, healthcare, energy and ecotourism • Global, regional and ASEAN partnerships and collaboration for knowledge transfer, technology exchange, and market access • Increased investment from private sector domestically or abroad in Thailand’s bioeconomy industries

Weaknesses	Threats
• Industrial and economic bias over environmental and social needs in the bioeconomy implementation power system. • Limited engagement from stakeholders in environmental and social sectors including government agencies or non-governmental sectors in the PPPs • Insufficient mechanisms supporting artisanal bioeconomy • Educational gaps in specialized bioeconomy training targeting smallholders	• Climate change-related events, such as droughts, floods and pest outbreaks, disrupting agricultural production and supply chains, impacting the reliability of bioeconomy feedstocks as raw materials for bioproducts • Uncontrolled expansion of bioeconomy activities leading to environmental degradation, biodiversity loss, and other negative impacts if not managed sustainably • Fluctuations in commodity prices, trade tariffs, and market demand affecting the profitability and sustainability of bio-based products produced in Thailand • Price and technology advantage of conventional industries, like fossil fuel, resisting the adoption of bio-based alternatives • Market competition from other countries with similar bioeconomy products

4. East African regional bioeconomy strategy and implementation

Bioeconomy has gained significant traction in recent years as a strategic framework for sustainable economic development, and its relevance in East Africa is becoming increasingly apparent (Virgin et al., 2022). East Africa faces diverse challenges ranging from climate change impacts to resource scarcity, and bioeconomy emerges as a promising avenue for fostering resilience and sustainable development. The region has rich biodiversity, including diverse plant and animal species, and unique ecosystems (Gatune et al., 2021). Sustainable management of these biological resources can unlock economic opportunities in industries such as pharmaceuticals, biotechnology and ecotourism. The region is largely arid or semi-arid, however, and bioresources can be somewhat scarce; consequently, circularity is normally incorporated directly to maximize bioresource value.

4.1 Circular bioeconomy strategy in East Africa

The circular bioeconomy in Eastern Africa has progressed while various challenges have emerged as the region transitions towards sustainable and regenerative economic models. Over recent years, there has been a growing recognition of the potential benefits of embracing circular principles, particularly in the context of addressing environmental degradation, promoting resource efficiency, and fostering economic resilience (Sekabira et al., 2022). The Bioeconomy Strategy for East Africa noted the importance of integrating circularity into policy frameworks related to waste management, renewable energy promotion, and sustainable agriculture (Virgin et al., 2022). Pilot projects and demonstrations showcasing circular bioeconomy practices are emerging across the region, serving as testbeds for innovative solutions and demonstrating the feasibility of circular approaches in diverse contexts (Lutta et al., 2024). The key policies and institutions promoted in the strategy, and the roadmap, are detailed and discussed below.

Policies and institutions

The bioeconomy in East Africa is at a critical juncture, characterized by both promising regional initiatives and the need for more nuanced national strategies. The region has made significant strides by developing an overarching regional bioeconomy strategy for 2022–2032, which needs to be transposed into policies and measures across the different countries (Virgin et al., 2022). The strategy focuses on the creation of new bio-based products that add value to bioresources in the region and/or use bioresources in novel, innovative and sustainable ways. Specifically, the scope of the strategy covers optimization and innovative use of biomass and biological resources produced from agriculture, aquaculture, bioprospecting and forestry, and includes alternative sources of food and feed as well as health and bioenergy-related products. Regional efforts towards policy harmonization are progressing, but there remains a need for countries to tailor their approaches to local conditions.

East African nations share similar agroecological zones, which present common challenges and opportunities in their bioeconomy sectors. This similarity has driven efforts towards the harmonization of policies across the region, aiming to create a cohesive regulatory environment. Harmonizing standards and regulations is essential for facilitating the development and commercialization of bio-based products. Such alignment encompasses quality standards, certification processes and environmental regulations, ensuring that products developed in one country can seamlessly access markets in others. The regional strategy is thus a recognition of the biophysical commonalities and economic interdependencies that call for more coordinated approaches and integrated markets.

The rise of new bio-based products from regional bioresources has highlighted the need for a unified framework for intellectual property (IP) laws in East Africa. A cohesive IP framework is critical for protecting innovations, encouraging investments, and facilitating the sharing of knowledge and technologies across borders. This framework would provide a fair and efficient system to support the commercialization of bio-based products, safeguarding the interests of innovators and stakeholders.

While the regional strategy sets a valuable framework, it is crucial for each East African country to develop its own dedicated bioeconomy strategy. This approach allows them to address unique local challenges and leverage specific bioresources effectively for sustainable development."

—Dr Julius Ecuru, Manager, BioInnovate Africa Programme

At the national level, each country must develop strategies that reflect their unique bioresources and socio-economic contexts. These strategies should be shaped through inclusive stakeholder engagement, ensuring they address the specific needs and opportunities of particular sectors (e.g. agriculture, forestry) and then adding the integrative bioeconomy perspective, which can help to articulate alternative pathways (Johnson et al., 2022). Engaging stakeholders through multi-stakeholder platforms will facilitate dialogue and collaboration, creating policies that are more responsive and comprehensive. Table 9 provides a summary of barriers and challenges and identifies key policy actions.

Table 9. Policy actions required for sustainable bioeconomy development in East Africa

Bioeconomy aspects	Barriers and challenges	Policy actions
Technology and infrastructure	• Limited access to advanced bioeconomy technologies • Inadequate R&D facilities • Poor infrastructure for bioproduct production and distribution	• Invest in and upgrade bioeconomy-related R&D facilities and technology parks • Provide incentives for private sector investment in technology and infrastructure • Develop biorefineries and biotechnology parks
Stakeholder engagement	• Lack of effective collaboration between government, private sector and local communities • Limited public awareness and education on bioeconomy benefits	• Establish multi-stakeholder platforms for regular dialogue and collaboration • Promote public awareness campaigns and educational programs on bioeconomy benefits • Engage local communities through participatory approaches
Social sustainability	• Inequitable benefit distribution among stakeholders· • Limited access to education and training for local communities • Social exclusion in bioeconomy opportunities	• Develop policies ensuring equitable distribution of benefits among all stakeholders • Provide educational programs and training for local communities to build skills and knowledge • Ensure inclusivity in bioeconomy opportunities through fair labour practices and community
Environmental sustainability	• Unsustainable exploitation of bioresources • Inadequate regulations to protect biodiversity and ecosystems • Pollution and waste management issues	• Develop and enforce regulations for sustainable bioresource management and biodiversity conservation • Implement waste management and pollution control measures • Promote environmentally friendly practices that reduce impact and enhance conservation
Economic sustainability	• High cost of bio-based product development • Lack of financial incentives for bioeconomy ventures • Competition from cheaper imported goods	• Provide tax incentives and subsidies for locally produced bio-based products • Enhance access to venture capital and funding for bioeconomy startups and SMEs • Implement procurement policies that favour bio-based products over imports

Building supportive infrastructure and capacity is essential for a thriving bioeconomy. Investments in biorefineries, biotechnology parks and efficient supply chain systems are necessary to meet the demands of bioproduct production and distribution. Equally important is building capacity through training programs and advisory services, which will equip small-scale producers and local communities with the skills needed to participate effectively in the bioeconomy and integrate into broader value chains. Ensuring environmental and social sustainability is another cornerstone of bioeconomy development. Implementing regulations for sustainable bioresource management will protect biodiversity and ecosystems, while promoting environmentally friendly practices minimizes impact and supports conservation. Social sustainability must be addressed by creating equitable opportunities for marginalized groups, promoting fair labour practices, and engaging communities meaningfully in bioeconomy activities. Improving access to venture capital and funding for bioeconomy startups and SMEs will drive growth and attract investment.

The roadmaps

A regional bioeconomy roadmap has generally not been expected since the region is not yet fully economically integrated like the EU, and thus roadmaps are left up to the country level. One country (Rwanda) has already developed a roadmap for its bioeconomy strategy; others have in some cases developed strategies for particular sectors (e.g. Sustainable Aviation Fuels in Ethiopia), and others have focused on long-term transformations for key systems such as agrifood (Virgin et al., 2024). We do not analyse the national level in this section on Eastern Africa, but some further approaches or experiences for roadmaps are mentioned briefly below.

Developing a roadmap for the implementation of a bioeconomy strategy in Eastern African countries requires a collaborative approach that addresses the unique challenges and opportunities within the region. One of the outcomes of the modern bioeconomy envisaged in the East African regional bioeconomy strategy was development of new value-added bio-based products from various bioresources to enhance climate resilience while adding value to the local economies of member countries. Establishing regional centres of excellence (CoEs) for bioeconomy research in East Africa is also needed to drive collaborative R&D, fostering partnerships between universities, research institutions and the private sector, which are vital for technological advancement. CoEs can vary in their scope, and in general are aimed at driving research on particular key crops (e.g. cassava) or in particular application areas such as bioenergy, vaccines, data science, internet of things (IoT), and natural resource management (Lutta et al., 2024; Virgin et al., 2024).

It can also be noted that although there is no regional roadmap for bioeconomy in Eastern Africa, there have been efforts at regional roadmaps in Africa for particular sectors. A prominent example of this is the African Union (AU) discussions and publications around Agenda 2063 with regard to transforming the agrifood sector. The AU takes the view that bioeconomy offers an integrative perspective allowing convergence between countries' nationally determined contributions (NDCs) and food system pathways on the one hand and two key regional strategies of the AU on the other hand. The two regional strategies are the Climate Change and Resilience Development strategy and the post-Malabo Comprehensive Africa Agriculture Development Programme (CAADP) agenda (Yamdjeu & Glatzel, 2024).

4.2. Bioeconomy visions at the regional level in East Africa and sustainability challenges

The East Africa Bioeconomy Strategy envisions a comprehensive approach encompassing policy development, institutional strengthening, partnership building, education and capacity building. The implementation of the East African Bioeconomy Strategy will require involvement and collaboration among communities, governments, research institutions, and private sector entities across the region. The stakeholders and the sustainability context are reviewed and synthesized in this section. The East Africa Science and Technology commission (EASTECO) and Bioinnovate Africa are two key organizations that have developed the vision and the resulting strategy, as explained further below.

Stakeholder analysis

Effective development and implementation of the bioeconomy in East Africa hinges on the comprehensive engagement and cooperation of diverse stakeholders. These include government bodies, the private sector, local communities, academic and research institutions, non-governmental organizations (NGOs), and the media. Each stakeholder plays a pivotal role in shaping and driving bioeconomy initiatives, ensuring that policies and strategies are not only robust and inclusive but also practical and sustainable.

Effective stakeholder engagement requires establishing mechanisms for regular dialogue and collaboration. Multi-stakeholder platforms can facilitate communication, allowing stakeholders to share insights, align goals, and develop joint initiatives. This collaborative approach ensures that bioeconomy policies and strategies are inclusive, responsive to local needs, and grounded in practical realities. It also helps in leveraging the strengths of different stakeholders, from policy development and research to community engagement and market implementation.

Each stakeholder brings unique strengths and perspectives that contribute to a holistic and sustainable bioeconomy framework. The private sector's involvement is fundamental to advancing the bioeconomy. Companies can drive the development and commercialization of innovative bio-based products by investing in research and technology, developing efficient production methods, and creating sustainable supply chains. Public-private partnerships are particularly effective in pooling resources and expertise to tackle challenges such as infrastructure development and market expansion. This can be done through the East African Business Council (EABC) which is the apex body of business associations of the private sector and corporates from the East African Countries (EAC). EABC is the voice of the private sector in East Africa and has Observer Status at the EAC level. This offers an authentic avenue to present and articulate the private sector agenda and concerns to the EAC Council of Minister and the Presidential Summit in a bid to inform policy decisions to facilitate trade and investments. The alignment of the private sector’s business strategies with sustainability goals can play a leading role in transitioning to a circular bioeconomy in the region.

In East Africa, the media plays a critical role in shaping public perception and awareness of the bioeconomy. Engaging the media is essential for promoting the benefits of a modern circular bioeconomy and educating the public about sustainable practices and bio-based products. Engaging media agencies in the region such as the East Africa editor's society, which brings together editor organizations in Eastern Africa, can foster greater and quicker acceptance of bioeconomy initiatives and encourage consumer demand for sustainable products. Media engagement is crucial for raising awareness and educating the public about the bioeconomy’s potential benefits. Highlighting success stories, explaining the advantages of bio-based products, and reporting on innovative technologies and practices can foster a positive perception of the bioeconomy. This helps build consumer demand and encourages wider societal support for sustainable initiatives, while also attracting investment by showcasing bioeconomy as a viable and progressive sector.

Sustainability and inclusivity

The pathway to a sustainable and inclusive bioeconomy in East Africa requires a balanced approach that integrates environmental stewardship with socio-economic development. Developing a sustainable and inclusive bioeconomy in East Africa presents a promising pathway for economic growth, environmental conservation and social equity. This approach leverages the region's abundant bioresources to create value-added products while addressing the pressing challenges of environmental degradation and socio-economic disparities. The integration of sustainability and inclusivity into the bioeconomy framework is crucial for ensuring long-term success and broad-based benefits.

For the bioeconomy to be truly inclusive, it must ensure that all stakeholders, particularly marginalized and vulnerable groups, have equitable access to opportunities and benefits (Dietershagen & Bammann, 2023). This includes smallholder farmers, women, youth and Indigenous communities who are often integral to the bioresource supply chain but may lack the resources and capabilities to fully participate in the bioeconomy. Policies should be designed to provide these groups with access to training, financial resources and markets. Establishing cooperatives and community-based organizations can empower local populations, enabling them to contribute effectively and share in the economic benefits generated by the bioeconomy.

> *To ensure sustainable bioeconomy development in East Africa, it is essential to integrate environmental stewardship with socio-economic development, ensuring that all stakeholders, particularly those from the informal sector, small holder farmers and the youth, have equitable access to opportunities and benefits. This requires tailored policies that support capacity building, address gender disparities, and empower local communities to participate fully in the bioeconomy."*
>
> —Muyambi Fortunate, Deputy Executive Secretary at East Africa Science and Technology Commission (EASTECO)

Inclusivity requires investment in capacity building and education to equip local communities with the skills and knowledge necessary to engage in bioeconomy activities. Training programs should focus on sustainable farming techniques, bioprocessing technologies and entrepreneurial skills. Educational initiatives should be accessible and tailored to the needs of different groups, ensuring that knowledge transfer is effective and relevant.

Addressing gender disparities is also critical for achieving an inclusive bioeconomy. Women play a crucial role in bioresource management and agricultural production in East Africa but often face barriers to participation in formal bioeconomy activities. Gender-sensitive policies should be implemented to support women's involvement in all aspects of the bioeconomy, from resource ownership to decision-making roles. Providing targeted support such as microfinance, training and access to markets can enhance women's economic empowerment and ensure their contributions are recognized and valued.

Regional collaboration is also important for the implementation of the bioeconomy strategy. Having similar resources and challenges, the Eastern Africa countries can gain from regional collaborations which facilitate knowledge exchange and transnational cooperation that empower disadvantaged countries. For certain key crops such as cassava, transnational networks are well established but need more support (Lutta et al., 2024). These build capacities and enable each country to learn from the others, tapping into methods and solutions that are developed or applied elsewhere and reducing information disparity among partner countries. Circular bioeconomy has a direct positive impact on the economic growth and environment in the region, but it can only reach its full potential through consistent collaboration across the countries (Sekabira et al. 2024). Partnerships that contribute to the development of new models, innovations, policies and investments in bioeconomy initiatives are vital for bringing the circular bioeconomy to action in East Africa (EASTECO, 2022)

4.3 Bioeconomy strategy implementation in East Africa

Implementation will require new infrastructure and institutions, with the latter emphasizing the establishment of policy frameworks and regulatory mechanisms to promote sustainable bio-based industries. Member countries have not been able to develop and enact policies that incentivize investment in bioeconomy initiatives while ensuring environmental conservation and social equity. While progress has been made, ongoing efforts are required to address challenges such as funding constraints, infrastructure gaps and regulatory barriers to fully unlock the potential of the bioeconomy in the region. Enabling actions and constraints are reviewed below.

Enabling actions

Significant efforts have been made to build institutional capacity and infrastructure to support bioeconomy activities through EASTECO and Bioinnovate Africa, who coordinate on development of R&D facilities, technology transfer mechanisms, and innovation hubs focused on biotechnology, agriculture, forestry, and other relevant sectors. These initiatives aim to enhance scientific knowledge, foster entrepreneurship, and facilitate commercialization of bio-based products and services.

Furthermore, partnerships and collaborations have been crucial in driving the implementation of the strategy. Governments, research institutions and industry players have forged alliances with international organizations, donor agencies and academia to leverage expertise, funding and resources. These partnerships have facilitated knowledge exchange, technology transfer and access to markets, thereby accelerating the growth of the bioeconomy in East Africa. Partnership and collaborations are evident through regional platforms such as the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), which is a subregional organization of the National Agricultural Research Systems (NARS) of 11 member countries, namely: Burundi; the Democratic Republic of the Congo; Eritrea; Ethiopia; Kenya; Madagascar; Rwanda; South Sudan; Sudan; Tanzania; and Uganda. ASARECA brings together scientists from the national agricultural research institutions of the member countries, national agricultural extension service providers and other

strategic development-oriented partners to generate, share and promote knowledge and innovations to solve common challenges facing agriculture in the member countries.

Education and awareness-raising campaigns have also played a vital role in promoting the bioeconomy agenda. Efforts to educate stakeholders about the benefits of bio-based industries, sustainable resource management practices, and the potential of biotechnology to address societal challenges have helped garner support and foster a conducive environment for innovation and investment. Education and awareness raising is currently done through regional CoE that were formed in the three East Africa nations of Kenya, Burundi and Tanzania. For example, through the East African Agricultural Productivity Programme (EAAPP) that was conceived as a Regional Agricultural Research for Development initiative, a regional CoE for cassava was established at Uganda's Namulonge Research Institute with the objective of developing policies and programs aimed at deepening cooperation in cassava research and policy among its member countries for the mutual benefit of all the stakeholders in the circular cassava economy. The regional centres enhance regional specialization in agricultural research, enhance collaboration in agriculture training and technology dissemination, and facilitate increased transfer of agricultural technology, information and knowledge across national boundaries. EAAPP is another regional partnership, bringing together the governments of Ethiopia, Kenya, Tanzania and Uganda with ASARECA and the World Bank. CoEs cover a wide range of activities, including training programs, vocational courses and academic curricula tailored to address the specific needs of the bio-based industries, ensuring a steady supply of skilled professionals and entrepreneurs (Virgin et al., 2024).

Constraints

Implementation faces several challenges that impede its progress and effectiveness. A fundamental challenge is the limited awareness and understanding of the bioeconomy concept among stakeholders, including policymakers, entrepreneurs and the public. Insufficient knowledge about the potential benefits of bio-based industries, sustainable resource management practices, and biotechnological innovations hinders support for bioeconomy initiatives and limits their uptake.

Another significant challenge is the lack of adequate funding and investment in bioeconomy initiatives. Limited financial resources hinder the development of essential infrastructure, such as research facilities and technology transfer mechanisms, and restrict the scaling up of bio-based industries. Moreover, access to financing for SMEs in the bioeconomy sector remains limited, constraining their ability to innovate and expand operations.

Infrastructure deficits, including inadequate transportation networks, energy supply, and storage facilities, also pose significant challenges to the bioeconomy's growth. Poor infrastructure not only increases production costs but also limits market access for bio-based products, particularly in rural areas where many bioresources are located. Addressing these infrastructure gaps requires substantial investment and coordinated efforts from governments and development partners.

Furthermore, regulatory barriers and policy inconsistencies hamper the development of the bioeconomy in East Africa. Complex and overlapping regulations, bureaucratic processes, and a lack of harmonization among countries create uncertainty for investors and hinder cross-border trade in bio-based products. Streamlining regulations, enhancing policy coherence, and strengthening enforcement mechanisms are essential to create an enabling environment for bioeconomy development.

Therefore, comprehensive education and awareness-raising campaigns are needed to build consensus, foster engagement and mobilize support for the bioeconomy agenda. Moreover, skills shortages and inadequate human capital pose significant challenges to the bioeconomy in East Africa. The lack of trained professionals, technicians and entrepreneurs with expertise in biotechnology, agriculture, forestry and related fields constrains innovation and hampers the growth of bio-based industries. Investing in education, vocational training and capacity-building programs is essential to develop a skilled workforce capable of driving the bioeconomy forward.

4.4 SWOT analysis of bioeconomy in East Africa

The implementation of a bioeconomy initiative in East Africa presents both significant opportunities and challenges. In terms of strengths, the region boasts abundant natural resources, including diverse flora and fauna, fertile land and favourable climate conditions, providing a solid foundation for bio-based industries. There is a growing demand for sustainable solutions globally, which offers a market for bio-based products from East Africa. Additionally, governments in the region are increasingly supportive of sustainable development initiatives, recognizing the potential of the bioeconomy to drive economic growth while addressing environmental concerns (Ecuru, 2016). Furthermore, there is untapped potential for innovation and technology development in sectors such as agriculture, forestry and biotechnology, which could fuel the growth of the bioeconomy in East Africa.

> *Although each country in Eastern Africa has its unique approach to addressing challenges, contextualizing solutions and optimizing transnational collaborations are crucial. We can advance the bioeconomy in the region and fully realize its potential for sustainable development, leveraging our shared challenges for collective growth by focusing on increased investment, streamlined regulations, and comprehensive education and capacity-building.*
>
> — Prof Ruth Oniango, Founder, Rural Outreach Africa

However, several weaknesses need to be addressed to ensure the successful implementation of bioeconomy initiatives. Inadequate infrastructure, including transportation, energy and processing facilities, poses a significant challenge to the efficient production and distribution of bio-based products. Moreover, there may be a shortage of skilled personnel and technical expertise in bioeconomy-related fields, requiring investments in education and training. Limited access to finance and investment capital for research, development and commercialization further hinders progress in this area. Additionally, complex regulatory frameworks, inconsistent policies and bureaucratic hurdles may impede the development and scaling of bioeconomy initiatives in the region.

Despite these challenges, there are numerous opportunities for the bioeconomy to thrive in East Africa. The growing global demand for sustainable products presents opportunities for East African bioeconomy initiatives to access international markets and generate export revenues. Value addition to existing agricultural and forestry sectors can create new markets for by-products, waste streams and renewable resources, contributing to economic growth and job creation, particularly in rural areas. Moreover, partnerships with international organizations, research institutions and private companies can facilitate knowledge transfer, technology exchange and access to markets, fostering innovation and collaboration in the bioeconomy sector.

However, there are also threats that need to be carefully considered and managed. Established industries may resist the adoption of bio-based alternatives, posing a competitive threat to bioeconomy initiatives in East Africa. Moreover, uncontrolled expansion of bioeconomy activities could lead to environmental degradation, biodiversity loss, and other negative impacts if not managed sustainably. Fluctuations in commodity prices, trade tariffs and market demand could affect the profitability and viability of bio-based products from East Africa. Additionally, climate change-related events such as droughts, floods and pest outbreaks could disrupt agricultural production and supply chains, affecting the reliability of bioeconomy feedstocks. Overall, while bioeconomy holds great promise for East Africa, addressing these challenges and leveraging opportunities will be crucial for its successful implementation and sustainable development (see Table 10).

However, significant challenges persist, including limited infrastructure, inadequate financing and capacity constraints, which hinder the scaling up of circular initiatives. The transition to a circular bioeconomy requires strong collaboration among governments, research institutions, businesses and civil society to drive policy reforms, promote technology transfer, and foster innovation.

Table 10. SWOT analysis of East African bioeconomy development

Strengths	Opportunities
• Rich biodiversity and natural resources suitable for bio-based industries, including diverse flora and fauna, fertile land, and favourable climate conditions • Growing market for bio-based products and Sustainable Solutions • Government support for bioeconomy and green transitions • Innovation and technology development in bioeconomy sectors	• Growing global demand for sustainable products • Value addition creating new markets for by-products, waste streams and renewable resources • Employment opportunities through value-added processing and manufacturing • Partnerships for knowledge transfer, technology exchange and access to markets

Weaknesses	Threats
• Inadequate infrastructure that hinders the efficient production and distribution of bio-based products • Limited technical expertise in bioeconomy-related fields • Limited access to finance and investment capital for research, development, and commercialization of bio-based products and technologies • Complex regulatory frameworks, inconsistent policies, and bureaucratic hurdles that impede the development and scaling of bioeconomy initiatives in the region	• Competition from conventional industries that may resist the adoption of bio-based alternatives in East Africa • Uncontrolled expansion of bioeconomy activities that could lead to environmental degradation, biodiversity loss, and other negative impacts if not managed sustainably • Fluctuations in commodity prices, trade tariffs, and market demand that could affect the profitability and viability of bio-based products from East Africa • Climate change-related events such as droughts, floods, and pest outbreaks that could disrupt agricultural production and supply chains, affecting the reliability of bioeconomy feedstocks

5. Cross-regional learnings and best practices in the Global South on implementation of bioeconomy strategies

This working paper has focused on the gap between strategies and implementation (the “meso” level of analysis). An important element of bioeconomy strategies – and the policies that support them – relates to supporting the role of SMEs, which have proven critical within innovation platforms for bio-based products and services (Trujillo et al., 2024). The meso level of strategy implementation is thus critically linked to the micro level. The key issues around the implementation of bioeconomy strategies were addressed in international workshops held in each of the three countries for their regions, as explained below.

5.1 Lessons from Nairobi, Kenya, workshop, November 2023

The national and subnational bioeconomy implementation was considered in terms of policy and strategy design, as well as the generation of governance spaces that allow the participation of multiple actors. In the East African context, this involves the transposition of strategies from regional to national levels, and in turn from national to subnational. Discussions in the regional workshop held in Nairobi underscored that while national bioeconomy policies are the principal drivers of progress, their effectiveness depends on how well they are translated and operationalized at subnational levels. Counties and local governments are on the frontlines of implementing bioeconomy initiatives, engaging communities, and aligning with local resource realities. Participants noted critical gaps in both national enabling frameworks and subnational institutional capacities, stressing the need for stronger national policies that also empower and resource subnational actors. National and subnational policies are therefore mutually reinforcing, as enabling frameworks at the top create coherence, while bottom-up implementation ensures relevance and impact. The challenges and recommendations discussed in the workshop are synthesized in Table 11.

Table 11. Challenges and solutions discussed in workshops for bioeconomy implementation in East Africa

Challenges	Recommendations
Absent subnational policies for bioeconomy development	Develop and implement subnational bioeconomy policies that align with national strategies, considering the linkages.
Lack of capacity for subnational institutions to design and implement effective bioeconomy policies	Build institutional capacity through training programs, knowledge exchange and collaboration with national and international institutions. Foster partnerships between local governments, research institutions and industry stakeholders.
Insufficient data on local bioresources, potential industries, and socio-economic conditions	Invest in data collection and analysis at the subnational level. Establish local databases and collaborate with research institutions to gather relevant information for informed decision-making.
Lack of coordination among subnational agencies, departments, and stakeholders	Establish coordination mechanisms, such as inter-agency task forces or committees, to facilitate collaboration. Encourage joint planning and implementation efforts among stakeholders.
Limited involvement of local communities in the development and implementation of bioeconomy policies	Create platforms for community participation in decision-making processes. Conduct awareness campaigns and involve local communities in bioeconomy strategy design to be inclusive.
Limited financial resources at the subnational level for bioeconomy initiatives	Advocate for dedicated funding streams for subnational bioeconomy projects. Explore public-private partnerships and leverage international funding opportunities. Prioritize projects that have both economic and social benefits.
Lack of alignment and integration of subnational bioeconomy policies with broader regional and national development plans	Ensure that subnational policies align with higher-level strategies. Encourage cross-sectoral collaboration to integrate bioeconomy considerations into various policy domains, such as agriculture, environment, and industry.
Limited skills and knowledge among local actors, including government officials, entrepreneurs, and community leaders	Implement capacity-building programs tailored to needs of local stakeholders. Provide training in areas such as sustainable resource management, entrepreneurship, and technology adoption.
Complex and lengthy regulatory processes that hinder the establishment of bioeconomy projects at the subnational level	Streamline regulatory processes, ensure transparency, and provide clear guidelines for obtaining permits. Establish regulatory support centres to assist businesses in navigating the regulatory landscape.
Limited mechanisms for monitoring and evaluating the impact of subnational bioeconomy policies and projects	Develop robust monitoring and evaluation frameworks. Establish performance indicators and regularly assess the progress of bioeconomy initiatives. Use feedback mechanisms to adapt strategies based on outcomes.

5.2 Lessons from Bangkok, Thailand, workshop, April 2023

During the workshop in Thailand, participants from the meso-level group[1] delved into the essential aspects of indicators and measurements, focusing on enhancing the strategies' effectiveness. They proposed indicators and measurements spanning economic and social dimensions. For economic indicators, there was a consensus on tracking the sustainability of startups over 2 to 3 years as a metric of success. Socially, participants emphasized gender equality within bioeconomy businesses and suggested incorporating self-reporting happiness assessments, akin to Thailand's BEDO model, to comprehensively gauge success, particularly in artisanal bioeconomy sectors.

Turning to the barriers and solutions of implementation of bioeconomy, representatives from Thailand, Malaysia and Cambodia discussed key challenges and proposed solutions. The key barriers included limited inclusivity in goal setting, inadequate industry financing, a shortage of high-skill workers, and the need for more effective success measurements. The proposed solutions revolved around integrating SDGs, fostering industry-driven financing mechanisms, prioritizing training and job creation, and implementing specific metrics like start-up longevity and gender equality indices.

1 The MICRO and MACRO group discussions are found in the companion chapters.

Yet the discussion left some questions unaddressed, notably concerning continuous engagement from marginalized populations in the bioeconomy and policies aimed at bolstering the environmental sustainability of bioeconomic projects. There is a lack of support mechanisms for enterprises, especially for those working on artisanal bioeconomy, to launch their business ideas, and inter-ministry collaboration is hindered as different ministries prioritize protecting their own resources. The question also remained of how to create an equitable value chain that fairly shares risks and benefits while ensuring farmers receive sufficient benefits. As summarized in Table 12, the workshop mainly highlighted the critical role of comprehensive indicators, targeted measurements, and innovative solutions in overcoming barriers to successful bioeconomy implementation.

Table 12. Challenges and solutions discussed in workshops about bioeconomy implementation in Thailand

Challenges	Recommendations
Lack of awareness and understanding in local communities of the bioeconomy and its associated benefits	Government agencies, like BEDO, could further extend the training on bioeconomy approaches and articulate its benefits to local communities.
Graduates often struggle to find suitable jobs in the biotechnology industry as their university degrees alone are insufficient to secure employment.	Government departments, like the Ministry of High Education, or the industry sector could facilitate upskilling labour and training recent graduates to meet industrial requirements.
Lack of financial support to implement bioeconomy strategies	Government and multilateral banks, such as the Asian Development Bank and the World Bank, can support bioeconomy through guarantees, low-interest loans and green bonds.
Lack of communication among multiple stakeholders	Organize multi-stakeholder seminars, conferences, and international meetings to improve communication and facilitate information exchange among stakeholders.

5.3 Lessons from Bogotá, Colombia, workshop, July 2023

During the workshop in Latin America, several discussions were held around the implementation of the Colombian national strategy, identifying at the meso scale its barriers, possible solutions and actions to be implemented.

The development of the bioeconomy in Colombia faces multiple structural and territorial challenges that hinder its widespread implementation and potential for sustainable transformation. Key barriers include the lack of financing, insufficient articulation among stakeholders, and the absence of a clear strategic vision, particularly in terms of public-private coordination and territorial priorities. To overcome these issues, the stakeholders recommended to secure financing from diverse sources – public, private, and international cooperation – while establishing national-level frameworks such as a Decree to guide bioeconomy actions, the development of Projects of National and Strategic Interest (PNSI), and the creation of a National Bioeconomy Agency to coordinate implementation efforts.

Additionally, the limited awareness and appropriation of bioeconomy concepts call for the design and execution of outreach campaigns targeted at civil society, government, academia, and the private sector. Strengthening value chains is also critical, requiring diagnosis of national and international market dynamics and the active participation

of anchor companies. Policies should shift towards territorial needs and opportunities, promoting localized bioeconomy models. To address low innovation capacities and weak infrastructure, it is essential to implement training programs, enhance technological adoption, and support long-term R&D initiatives. Furthermore, incentives for businesses must be established to encourage the production and commercialization of bio-based products and services, ensuring that the bioeconomy becomes a viable and inclusive development pathway across regions.

These challenges and recommendations are summarized in Table 13.

Table 13. Challenges and solutions discussed in workshops for bioeconomy implementation in Colombia

Challenges	Recommendations
Lack of financing	Secure financing from multiple sources (public, private, international cooperation).
Lack of articulation and strategic vision, including a lack of public-private coordination to know the territorial priorities and thus leverage them	• Develop the PNSI (Projects of National and Strategic Interest) of bioeconomy. • Create a Decree that guides bioeconomy actions at the national level. • Create the National Bioeconomy Agency, which is constituted as a Coordination Body for the implementation of the bioeconomy policy.
Divulgence of policies and the concept of bioeconomy	Design and implement a campaign to appropriate and divulgate the bioeconomy approach aimed at stakeholders (civil society, public and private entities, and academic sector).
Weak value chains, which includes a lack of knowledge of the value chains at the national level and of the supply and demand of the markets	• Prioritize and develop value chains. • Diagnose value chains and supply/demand in the national and international market. • Ensure participation of anchor companies in strengthening chains.
Preconceived development model not based on needs in the territory	Promote the bioeconomy based on the needs and opportunities of each territory.
Lack of incentives for the business sector for promoting bio-based products and services	Create a National Incentive Program for the business sector.
Low capacities installed in the territory for technological development and innovation activities, and lack of generation of human skills and capabilities	• Create training programs in the territory for civil society with support from governments. • Provide qualification and training for bioeconomy and local communities. • Support long-term R&D programs for execution (minimum 5 years). • Ensure bioeconomy information and support spaces are available in the territories.
Lack of infrastructure and communications in the regions	Strengthen the adoption of technology in companies and communities.
Limitations for value addition and sophistication processes for the generation of bioproducts	• Support long-term R&D programs for execution (minimum 5 years). • Ensure bioeconomy information and support spaces are available in the territories.

5.4 Cross-regional learning and comparison

Adopting a consistent methodology across the three workshops, we have been able to identify learnings and best practices at the meso level regarding governance, financial support, and capacity building, indicators and goals of bioeconomy policies from the three regions. These findings are presented in Table 14.

Table 14. Highlights of cross-regional learnings and best practices in the Global South on meso-level bioeconomy strategy implementation based on workshops in Thailand, Colombia and Kenya in 2023

Elements of bioeconomy policy	Learnings and best practices from the Bangkok, Thailand workshop	Learnings and best practices from the Bogotá, Colombia workshop	Learnings and best practices from the Nairobi, Kenya workshop
Monitoring and evaluation	• Suggested economic indicator: the number of startups still running after 2–3 years • Suggested social indicator: involvement of marginalized populations such as women, and gender equality in specific	• Supply chain indicators and monitoring for different agricultural commodities • Further development and application of sustainability agreements for commodities	• Development of robust monitoring and evaluation frameworks • Establishment of performance indicators and regular assessment of the progress of bioeconomy initiatives • Usage of feedback mechanisms to adapt strategies based on outcomes
Capacity building	• Multi-stakeholder collaboration in the value chain to support each other, especially farmers, and ensuring knowledge and skills are shared consistently to achieve an inclusive equitable environment in the value chain	• Develop bioeconomy based on the unique needs and opportunities of each territory • Training provided by local and regional governments at the subnational level for civil society • Strengthening the adoption of technology used by companies and communities • Enhancing partnership with academia for R&D	• Implementation of capacity-building programs tailored to the needs of local stakeholders • Providing training in areas such as sustainable resource management, entrepreneurship, and technology adoption
Financial support	• Program Management Unit for Competitiveness to manage research funding • Environmental funds from various authorities to provide budgets and increase access to international funds for bioeconomy projects	• Financing from multiple sources (public, private, international cooperation) • Identification of the most market-oriented opportunities through diagnosis of value chains and market supply/demand	• Advocacy for dedicated funding streams for subnational bioeconomy projects • Exploration of public-private partnerships and leveraging international funding opportunities • Prioritization of projects that have both economic and social benefits

The comparison across the three regions reveals a number of similarities in terms of addressing the gap between bioeconomy strategies and their implementation. As the discussion and analysis crosses over three different jurisdictional or institutional levels (local or subnational, national, and regional), it has also provided some insights into the multi-level nature of bioeconomy development and the inter-linkages across levels. The four elements identified in Table 13, although not exhaustive in terms of addressing the implementation gap for bioeconomy strategies, can offer a cross-sectional and cross-regional or global view on the key requirements across the different levels:

- **Monitoring:** This was identified as critical in all regions and requires gathering data at local or subnational levels, but it can be applied at different levels, ranging from specific commodities to the overall performance of bio-based sectors. The workshops emphasized the importance of using specific indicators – such as the survival rate of startups, gender equality, and supply chain sustainability – to track progress. Robust frameworks should incorporate feedback loops to adapt strategies over time and include sustainability agreements for agricultural commodities to ensure long-term impact.

- **Capacity building:** This includes a wide range of activities and stakeholders, ranging from general awareness to specific training for farmers on supply chains. All workshops agreed on the need for multi-stakeholder collaboration and context-specific training programs. This includes supporting farmers and marginalized communities, promoting technology adoption, and enhancing ties with academia for R&D. Local and regional governments were highlighted as key actors in providing technical and entrepreneurial training that reflects the needs and opportunities of specific territories.

- **Financial support:** A broad base of sources and partnerships for financial support was deemed necessary, as well as a need for mechanisms to combine social and economic benefits. Successful strategies involve securing funding from diverse sources including public, private, and international cooperation, as well as setting up dedicated program management units or environmental funds. In Nairobi, there was a strong call for public-private partnerships and prioritization of projects with both economic and social benefits.

- **Governance:** Highly inclusive processes are needed to bring together farmers, the private sector, and development agencies to ensure consistency and coherence. Experiences across the three workshops stressed the importance of integrating bioeconomy efforts with other sectors, engaging communities and MSMEs in decision-making, and reducing bureaucratic barriers through coherent and coordinated policy instruments – such as Colombia's proposal for a National Bioeconomy Agency.

These key elements and similarities in approach and orientation across different regions confirmed the cross-cutting and unifying nature of bioeconomy that offers new development pathways, while at the same time raising challenges precisely because the highly integrative view challenges sectoral perspectives and requires stronger policy coherence and multi-level governance.

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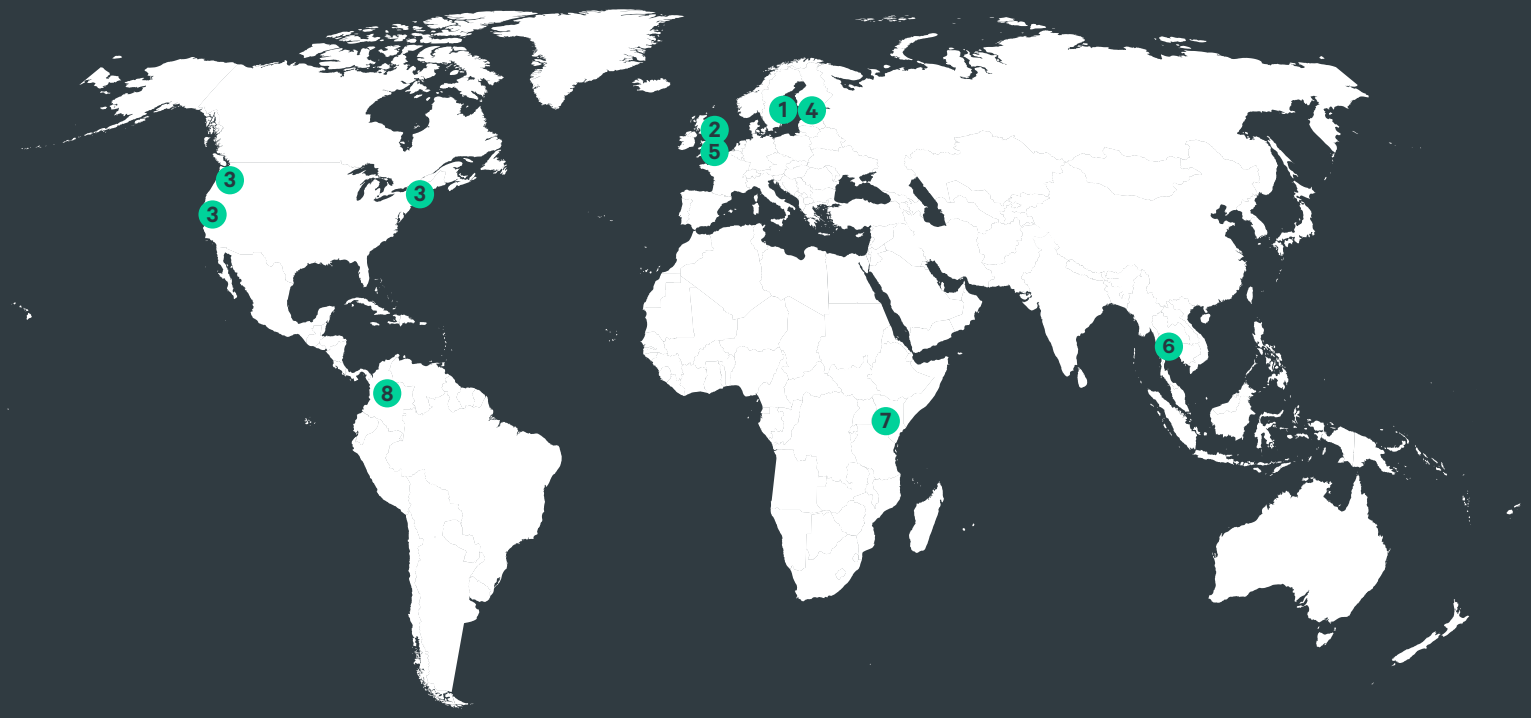

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