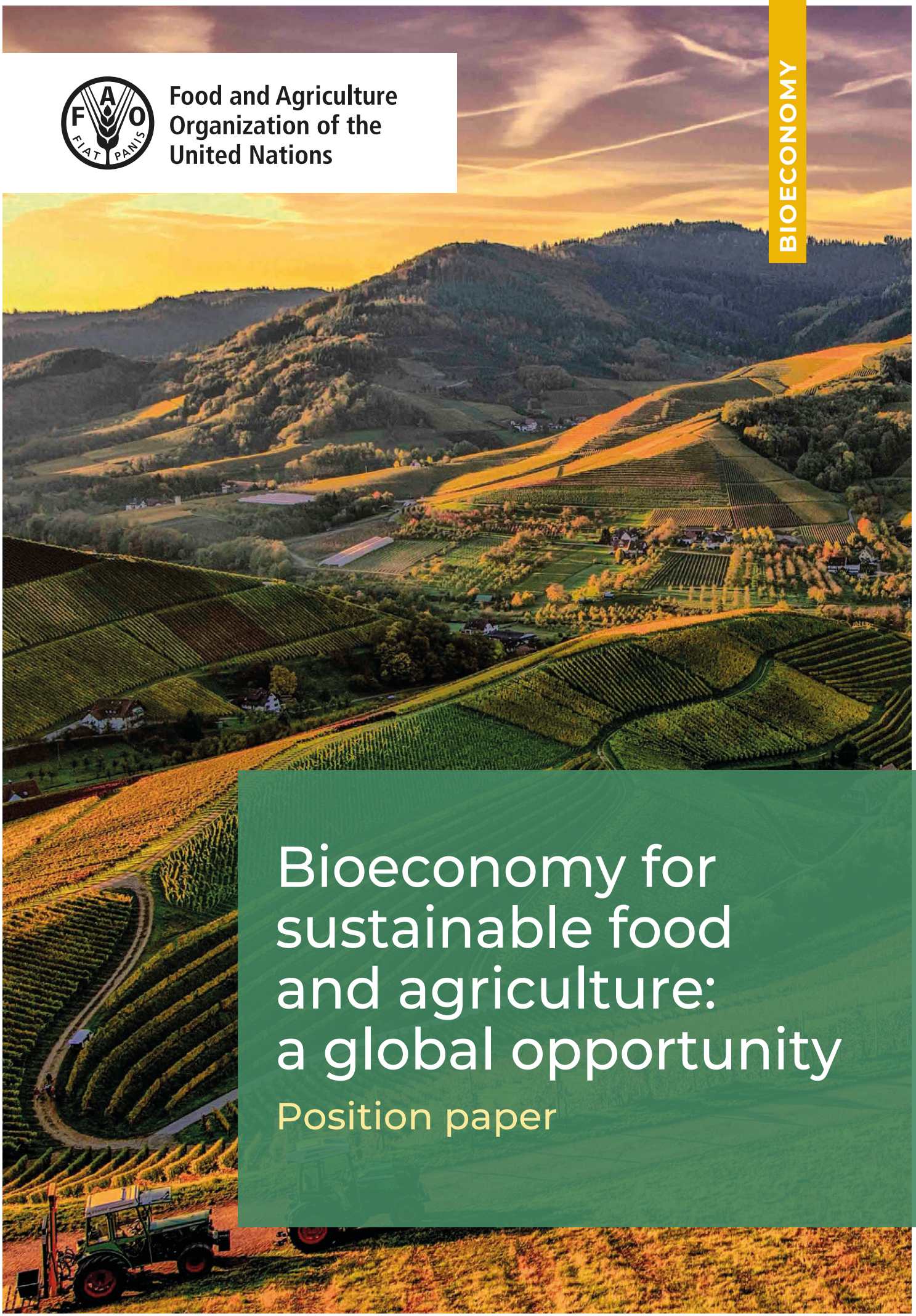

Food and Agriculture Organization of the United Nations

BIOECONOMY

Bioeconomy for sustainable food and agriculture: a global opportunity

Position paper

Bioeconomy for sustainable food and agriculture: a global opportunity

Position paper

Food and Agriculture Organization of the United Nations (FAO)
Rome, 2024

Required citation
FAO. 2024. *Bioeconomy for sustainable food and agriculture: a global opportunity – Position paper.* Rome. https://doi.org/10.4060/cd1976en

ISBN 978-92-5-139032-0

Cover photograph: © Pexels, Christian Heitz. Integrated agricultural systems play a crucial role in supporting bioeconomy by combining traditional knowledge with modern technological advancements.

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Acknowledgements

The report was prepared by the FAO Office of Climate Change, Biodiversity and Environment. Lucia Gardossi, Associate Professor of Organic Chemistry at the Department of Chemical and Pharmaceutical Sciences of the University of Trieste acted as the lead author.

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The authors would like to thank Alexandre Meybeck (Senior Technical Advisor, FAO Natural Resources and Sustainable Production stream), Vicente de Azevedo Araújo Filho and Daniel Boeira Lodetti (G20 Initiative on Bioeconomy, Brazilian Ministry of Foreign Affairs) for their careful review.

Acknowledgements also to Gordon Ramsay for editing and proofreading this document, as well as to the graphic designers for their excellent work.

A innovative bioeconomy combines traditional and high-tech technologies.

Abbreviations

CBD	Convention on Biological Diversity
FAO	Food and Agriculture Organization of the United Nations
GBF	Global Biodiversity Framework
GIB	G20 Initiative on Bioeconomy
IPCC	Intergovernmental Panel on Climate Change
ISBWG	International Sustainable Bioeconomy Working Group
JRC	Joint Research Centre [of the European Commission]
SDGs	Sustainable Development Goals

Baobab fruit, oils and products.

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Executive summary

Making a transition to a sustainable bioeconomy can help us move toward a low-carbon future where we are less reliant on fuels and materials derived from non-renewable fossil resources and will play a critical role in meeting international commitments to urgently address climate change and biodiversity loss. It can also contribute to reaching many of the other development objectives and targets enshrined in the Sustainable Development Goals and other multilateral agreements regarding food security and nutrition, poverty reduction, and inequality.

FAO has much to offer in discussions on bioeconomy. Crop and livestock production, fisheries and aquaculture, and forestry generate the biomass and biological resources that provide the foundation of a sustainable bioeconomy. The agricultural sectors will also play a central role in ensuring that biomass can be steadily circulated throughout the entire bioeconomy in ways that optimizes the use of biological resources. The complex and diverse agrifood systems that produce, process and distribute food, feed, fibres, fuel and other products that all of us depend on will clearly need to be on the top of the agenda in any discussions about how to move toward a sustainable bioeconomy. The bioeconomy should be seen as a motor for transforming agrifood systems so that they become more efficient and productive, equitable and resilient, and support ecosystem health.

This paper provides a set of eight recommendations to guide global discussions on the bioeconomy:

Recommendation 1: Achieve food security and nutrition through the transformation of agrifood systems, as a primary principle for developing the bioeconomy agenda. Promote the development of bioeconomy policies, strategies, and plans that prioritize food security and nutrition for all, particularly vulnerable populations, and mainstream the transformation of agrifood systems so that they become more efficient, equitable, resilient, and sustainable.

Recommendation 2: Leverage the potential of the bioeconomy to enable holistic carbon management, alleviate pressure on natural resources and address climate change. Encourage the development of comprehensive national renewable carbon management plans that integrate the bioeconomy as a key component; and promote the diversification of biomass sources for multiple uses, sustainable land management, carbon capture and utilization, waste-to-energy processes and other bioeconomy options. This should be done by developing and enforcing robust sustainability criteria and certification schemes for biomass production and use; fostering multi-stakeholder collaborations; and investing in research and development to advance innovative carbon management technologies and practices.

A sustainable bioeconomy translates knowledge from older generations to biological sciences for the future.

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Recommendation 3: Scale up investments in science, technology, and innovation for agrifood systems in the bioeconomy. Commit to increasing investment and creating an enabling environment to improve access to finance and the transfer of technological innovations that can transform agrifood systems. Give particular attention to Small Island Developing States, low- and middle-income countries, and vulnerable groups. Support and encourage efforts by multilateral institutions and international financial institutions to develop dedicated criteria and indicators for bioeconomy investment and mobilize additional resources to meet the demand of agrifood systems.

Recommendation 4: Develop holistic, practical and transparent bioeconomy policies, strategies and plans. Bioeconomy policies, strategies, and plans should be tailored to national circumstances and capacities. At the same time, there needs to be policy coherence among the sustainable development frameworks and the goals of the multilateral environmental agreements of relevance to bioeconomy across different sectors at the local, national, regional, and international level. The use of transparent criteria and methodologies for monitoring and evaluating the sustainability of bioeconomy activities is essential.

Recommendation 5: Promote the bioeconomy for rural-urban transformation. Promote inclusive and equitable bioeconomy development in rural and urban areas by supporting local bio-based value chains that valorise waste, residues, and by-products; decentralized biomass processing; and rural and urban entrepreneurship and innovation through policy incentives, technical assistance, training, and investment.

Fisheries, Thailand.

© FAO/Sirachai Arunrugstichai

Recommendation 6: Harness the potential of the bioeconomy for inclusive development and a just transition. Recognize and integrate the principles of a just transition in bioeconomy policies, strategies, and plans. Make sure that no one is left behind by ensuring that small-scale agricultural producers, Indigenous Peoples, women, youth, and other vulnerable groups are included and have equal opportunities to participate in the bioeconomy including through greater investment in education, training, and empowerment of youth, women, and other social groups.

Recommendation 7: Establish globally accepted criteria for sustainable bioeconomy. Support the development of globally accepted sustainability criteria for the bioeconomy that are underpinned by empirical data, closely aligned with the SDGs.

Recommendation 8: Foster global cooperation for sustainable bioeconomy. The coordinated and synergistic actions needed to advance sustainable bioeconomy development would be bolstered by the establishment of a global multi-stakeholder platform with the participation of United Nation institutions. This platform could act as a catalyst for developing bioeconomy policies, strategies, and plans; building capacities and knowledge networks; and creating incentives at global, regional, national, and sub-national levels.

Traditional and modern agricultural systems.

© FAO/Marta Gomez San Juan

Introduction and rationale

Ensuring food security and nutrition is a paramount objective at the core of the development of a sustainable bioeconomy. Agrifood systems play a central role in this endeavour. They serve as the foundation for building the capacity of bioeconomy to address global challenges in a holistic and regenerative manner. This paper focuses specifically on the role of actions that can ensure food security and nutrition and at the same time transform agrifood systems so that they advance the development of the bioeconomy and enhance its sustainability.

This paper has been prepared by FAO to inform the current discussions on bioeconomy including in the G20 Initiative on Bioeconomy (GIB). In this context the paper also contributes to the discussions around the High-Level Principles on Bioeconomy at the GIB.

The GIB builds upon the outcomes of recent G20 Summits (G20 India, 2023). These meetings have highlighted the potential of the bioeconomy to respond to global social, environmental, and economic challenges; the need to co-design more effective bioeconomy governance mechanisms and monitoring systems to implement a sustainable and regenerative bioeconomy (Gardossi *et al.*, 2023); and the role of the bioeconomy in improving natural resource management, soil conservation, and agricultural production (G20 Argentina, 2018).

A Maasai tribesman cutting bark off a mkunde kunde tree for abdominal pain in animals and humans.

© FAO/Giuseppe Bizzarri

The political commitment to bioeconomy and the increasing interest in its expansion is reflected in the growing number of dedicated bioeconomy strategies worldwide. As of July 2024, FAO has identified 23 countries with dedicated bioeconomy strategies: Austria, Brazil, Canada, China, Colombia, Costa Rica, Estonia, Finland, France, Germany, Ireland, Italy, Japan, Latvia, Malaysia, Namibia, Norway, Portugal, South Africa, Spain, Thailand, Kingdom of the Netherlands, and the United States of America. Additionally, there are three multi-country strategies for the Eastern Africa Community, the European Union, and the Nordic Council of Ministers.[1] These strategies provide different definitions of bioeconomy, and outline the priorities and actions linked to the impact of bio-based economic sectors (primary, secondary, and tertiary[2]) on their respective economies and ecosystems (Dubois and Gomez San Juan, 2016; IACGB, 2024).

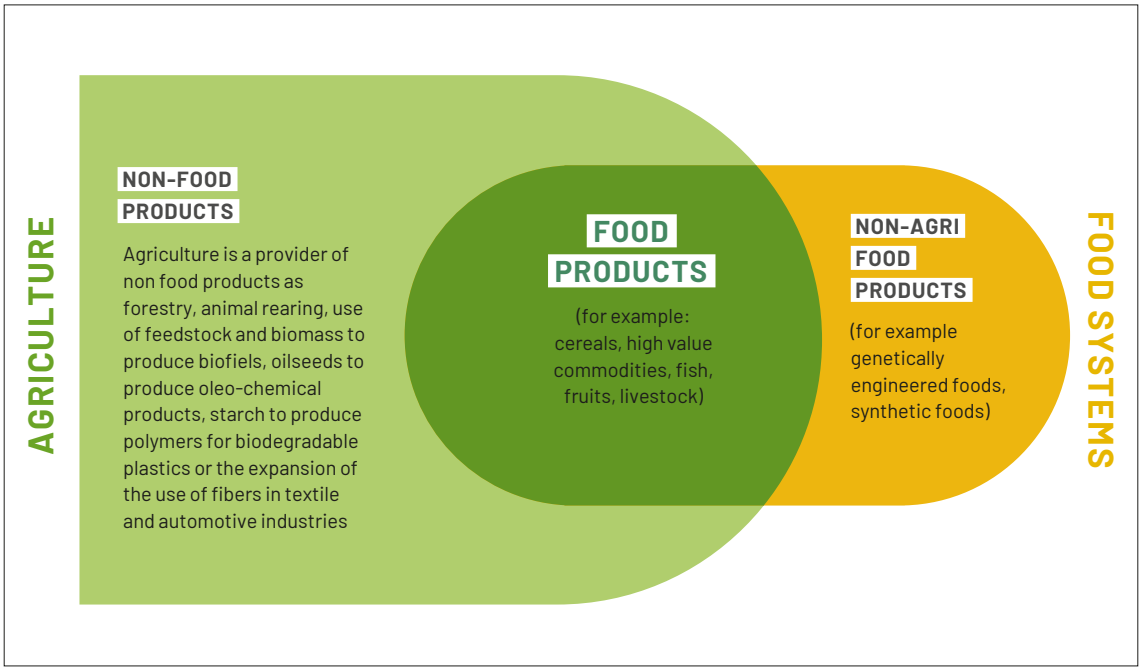
[1] The FAO bioeconomy dashboard analyzes two datasets, focusing on global bioeconomy strategies and their alignment with biodiversity and climate action, and food system transformation pathways. The dashboard also provides information on various national official documents and plans on sectors that are part of the broader bioeconomy (FAO, 2024a).

[2] The primary sector of the bioeconomy involves the direct extraction and harvesting of biological resources. This includes activities such as cultivation of crops, the management and harvesting of forest resources, fisheries, and aquaculture. These activities provide the raw materials for other sectors of the bioeconomy. The secondary sector of the bioeconomy pertains to the processing and transformation of biologically derived raw materials into finished products (e.g. food processing, wood and paper manufacturing) and the production of bio-based chemicals and materials (e.g. bioplastics and biofuels). This sector adds value to the raw materials obtained from the primary sector by converting them into more refined and usable forms. The tertiary sector involves the provision of services related to the use and management of biological resources (e.g. ecotourism, ecosystem services, bioeconomy education, research and development, bioeconomy-related financial services, and consultancy services)(Gomez San Juan and Bogdanski, 2021).

Chapter 1
Bioeconomy for food security and nutrition

Agrifood systems cover the journey of food (e.g. cereals, vegetables, fish, fruits and livestock) from farm to table. This journey includes food production, harvesting, processing, packaging, transport, distribution, trade, marketing, preparation, consumption and disposal. Agrifood systems also include non-food products (e.g. wood and non-wood forest products, bioenergy, animal hides, cotton, and other fibers) that provide livelihoods to millions. They also encompass the activities, services, investments and decisions that play a part in sustainable consumption (Figure 1) (FAO, 2021a). The bioeconomy is a key pathway for making the transition to more efficient, inclusive, resilient, and sustainable agrifood systems in a way that leaves no one behind (FAO, 2021b; FAO, 2023a).

Figure 1. **Agrifood systems definition**



Source: **FAO.** 2021a. *Conference Forty-second Session. Agriculture Food Systems Transformation: From Strategy to Action.* Rome. www.fao.org/3/nf649en/nf649en.pdf

The bioeconomy integrates a range of economic sectors, including the food and agriculture sector. It also provides a cross-cutting framework that can be adapted to shape different institutional mandates, depending on the national circumstances and capacities of a given country. It is a versatile concept that transcends the boundaries of individual industries and offers a holistic approach to harnessing biological resources in a sustainable and innovative manner (FAO, 2021c).

The diversity of approaches for developing a sustainable bioeconomy reflects regional, national, and sub-national circumstances and capabilities. This diversity has the potential to foster the collaboration of bioeconomy stakeholders at all levels. Fifteen common sustainability objectives have been identified. They address the environmental, social and economic dimensions of sustainability and emphasize good governance (Gomez San Juan and Bogdanski, 2021). Among major objectives are safeguarding food security; substituting fossil-fuel-based products with sustainable bioproducts; creating incentives for the efficient use of biological resources while protecting biodiversity, water, and soil and climate action; creating jobs and revitalizing rural, peri-urban, coastal and other areas; and establishing new fair and equitable value chains (see Appendix 2).

These sustainability objectives constitute a shared foundation for the various bioeconomy strategies. This is true even if not all the strategies incorporate every objective or combine them in the same way. Most bioeconomy strategies also include dedicated governance structures and actions to create an enabling environment (Gardossi *et al.*, 2023). They also outline monitoring systems to track the progress being made towards achieving strategy sustainability objectives (see Section 3).

Every country is confronting different challenges that require different solutions. Nevertheless, all bioeconomy strategy documents express the need to make a transition from fossil-based resources to more sustainable renewable biological resources. This places the agrifood systems at the heart of the bioeconomy, as these systems are responsible for the production of renewable biological resources. These resources include food and non-food crops, forest and fisheries products, industrial side streams, by-products and organic waste.

Food security is a primary objective for a half of the existing dedicated national bioeconomy strategies and regional strategies and is seen as an important element in the rest (Appendix 2). However, gaps remain in global bioeconomy development, and FAO is working to address these gaps (Appendix 3). Box 1 presents an overview of the FAO corporate priority on bioeconomy and key work areas.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Recommendation **1**

Achieve food security and nutrition through the transformation of agrifood systems, as a primary principle for developing the bioeconomy agenda

Promote the development of bioeconomy policies, strategies, and plans that prioritize food security and nutrition for all, particularly vulnerable populations, and mainstream the transformation of agrifood systems so that they become more efficient, equitable, resilient, and sustainable.

Box 1

Bioeconomy at FAO

The working definition of bioeconomy that has been adopted by FAO in the context of the Strategic Framework 2022–2031 Programme Priority Area is: "the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy".

FAO facilitates approaches for overcoming the challenges that agrifood systems are facing and gives particular attention to low- and middle-income countries. Activities related to science, technology, and innovation figure prominently in the Organization's work and are in alignment with its mandate and core functions. In the new FAO vision, urgent issues connected to food and agriculture, people's livelihoods and wellbeing, and the preservation of natural resources are not addressed in isolation. The Organization is committed to achieving in an integrated way the 'four betters': better production, better nutrition, a better environment and a better life. With this perspective, FAO strives to promote bioeconomy to enhance the sustainability, inclusivity, and competitiveness of agrifood systems. By harnessing sustainable agricultural practices and incorporating the latest agricultural technologies, the bioeconomy can make agrifood systems more efficient, resilient, equitable, and sustainable. When agrifood sectors become better able to sustainably provide more renewable raw materials, the bioeconomy can then contribute to the sustainability efforts of other sectors beyond agriculture (e.g. construction, textiles, pharmaceuticals). This delivers wide-ranging positive benefits for livelihoods, human health, climate, and the environment.

FAO and its Members have elevated bioeconomy to the level of a strategic priority within the 2022–31 Strategic Framework. The Programme Priority Area, 'Bioeconomy for sustainable food and agriculture', focuses on two main areas of action: (i) facilitating the deployment of innovations that increase resource use efficiency, improve environmental outcomes in agrifood systems and prevent pollution; and (ii) providing support to countries, regions and institutions in developing and implementing integrated, evidence-based bioeconomy strategies, policies and programmes.

The work of the programme encompasses four functions: (i) providing policy support (e.g. bioeconomy principles, criteria, indicators and data, and strategies and policy guidelines); (ii) building capacities in countries through science, technology and innovation and the mainstreaming of gender, youth and Indigenous Peoples perspectives into bioeconomy initiatives; iii) fostering partnerships, particularly through the International Sustainable Bioeconomy Working Group (ISBWG), which was established in 2016; and (iv) generating knowledge and advocating for policies and initiatives that address various dimensions of food security. The programme provides a full package of support, from policy formulation to the transfer of data and technology. It has established FAO as a neutral facilitator for global dialogues and exchanges of experiences on bioeconomy for sustainable food and agriculture. By bringing together the Organization's vast and diverse technical expertise, the Programme ensures that Members receive support tailored to their specific needs for bioeconomy development and monitoring.

Biological resources produced by the agrifood sectors are key feedstocks for making a transition from fossil-based resources to renewable carbon feedstocks (so called "defossilization") (Carus, 2020). This transition is being undertaken in many secondary production sectors (Annevelink *et al.*, 2022; Zuiderveen *et al.*, 2023). Agrifood systems provide the necessary biomass, biological resources and ecosystem services for a well-functioning sustainable bioeconomy (Giuntoli *et al.*, 2023). But they are in need of innovation to become more efficient and productive and reduce negative environmental impacts (see Section 2.2), including their contribution to the accumulation of greenhouse gases in the atmosphere.

Global emissions from the agrifood systems already amount to 16.2 billion tonnes of CO_2 equivalents or about a third of global anthropogenic greenhouse gas emissions. These emissions are generated on farms, by pre- and post-production processes, and through land-use change (FAO, 2023b). Sustainable bioeconomy development could reduce the amount of greenhouse gases emitted by agrifood systems and increase the resilience of these systems. Examples of bioeconomy innovations that can enhance the resilience of agrifood systems to extreme climate and weather-related events and other shocks, include sustainable production practices, such as agroforestry, integrated crop-livestock systems, and conservation agriculture, that promote biodiversity and regenerate ecosystems.

The global agriculture value-added sector has grown by 84 percent over the last 20 years, reaching USD 3.7 trillion (FAO, 2023b). This growth is attributable to a combination of factors, including the increased use of irrigation, pesticides and fertilizers, and to a lesser extent the expansion of the area under cultivation, better farming practices and the use of bio-innovation and biotechnologies (e.g. high-yield crops). However, in some contexts unsustainable agricultural practices have had a detrimental effect on the ecosystems that underpin the production of food and other biomass-based products. Biodiversity loss, water scarcity, and the conversion of carbon-sequestering natural habitats to other uses have all been exacerbated by the current model of biomass production and utilization. Almost 75 percent of the negative impacts on land-based biodiversity can be attributed to agriculture, and forestry accounts for an additional 23 percent (UNEP, 2024). The impacts from agriculture are associated with primary production at the start of the value chain. Since 2000, the use of pesticides has surged by 62 percent, and the application of inorganic fertilizers has increased by 44 percent (FAO, 2023b).

1.1 THE LIMITS OF BIOMASS USE AND A HOLISTIC APPROACH TO CARBON MANAGEMENT

The design and implementation of sustainable bioeconomy strategies and plans require an assessment of the limits of the biomass that agrifood systems can provide. This is critical if the biomass is to replace fossil carbon and meet the demand for different products of current production systems globally without making unacceptable trade-offs with other sustainability objectives (e.g. food security and biodiversity conservation) (Gomez San Juan, 2024). The assessment of biomass availability is complicated since climate change is threatening sustainable production and utilization of biological resources. Higher temperatures and extreme weather events (e.g. droughts, floods, and heatwaves) reduce crop yields, especially in tropical regions. Climate change has impacts on rangelands and

pastures, reducing the quality and quantity of feed for livestock and lowering the productivity of livestock systems. Rising ocean temperatures and acidification are threatening fisheries by disrupting marine ecosystems and fish migratory patterns. More frequent and intense climate shocks make food production and food access increasingly unstable and unpredictable year-to-year (FAO, 2022a).

Data show that the biomass currently produced worldwide is not enough to meet the carbon demand for materials and energy production. Over the past five years, the annual global demand for terrestrial biomass was about 13.5 billion tonnes or 6.75 billion tonnes of carbon. Fifty-six percent of this biomass was used for animal feed; 16 percent for bioenergy production; 15 percent for food; and 11 percent for material use (Skoczinski *et al.*, 2024). Only two percent was used to produce advanced biofuel, and 0.03 percent for bio-based polymers. During the same period, the annual consumption of fossil feedstocks for energy production alone was about 11.8 billion tonnes of oil equivalent, which corresponded to an estimated carbon content of about 9.9 billion tonnes (Kircher, 2022). These figures indicate that the current global biomass production falls short of meeting the escalating carbon demand. To meet the energy sector's demand for non-fossil feedstocks, solar, wind, geothermal and hydropower are expected to drive the decrease of carbon used for energy production (Centi, Quadrelli and Perathoner, 2013). Carbon demand is more crucial for the material sectors. The materials and chemicals sectors, unlike the energy sector, require carbon as an essential building block. These sectors depend on either fossil resources or biomass. The global carbon demand for organic chemicals and their derivatives currently stands at 550 megatonnes of embedded carbon per year (Kähler, Porc and Carus, 2023). Carbon management plans would allow to better plan and to improve efficiency in the use of carbon for different materials within the bioeconomy (Box 2).

Recommendation **2**

Leverage the potential of the bioeconomy to enable holistic carbon management, alleviate pressure on natural resources and address climate change

Encourage the development of comprehensive national renewable carbon management plans that integrate the bioeconomy as a key component; and promote the diversification of biomass sources for multiple uses, sustainable land management, carbon capture and utilization, waste-to-energy processes and other bioeconomy options. This should be done by developing and enforcing robust sustainability criteria and certification schemes for biomass production and use; fostering multi-stakeholder collaborations; and investing in research and development to advance innovative carbon management technologies and practices.

Box 2

Carbon management and the climate change mitigation potential of forest-based products

Accurate, precise, transparent and complete estimates of carbon storage in forest products, over time and by country, can underpin international agreements on managing greenhouse gas emissions and help in formulating sustainable development strategies. FAO analysis and data are already available to estimate the carbon pool in harvested wood products (e.g. paper, sawn wood and wood panels). Estimates of the climate change mitigation potential of harvested wood products can support decision-making and policy design in forest management, material recycling programmes, and many other sectors. These estimates may also help incentivize the production of certain products. They can also facilitate decisions on whether to export raw materials for added value or build new domestic production facilities. Improved capacity to quantify climate change mitigation potential is also important to stimulate economic activity associated with the production and sale of sustainably sourced and produced wood products, which is in line with Sustainable Development Goal 8, SDG 8 (Decent Work and Economic Growth) and SDG 15 (Life on Land).

The bioenergy plays a crucial role in the bioeconomy in many countries and should be assessed in carbon management strategies. These assessments need to carefully consider local circumstances. They should also take into account that energy may also be obtained from non-carbon sources. As noted earlier, materials and chemicals will always need carbon-based feedstocks. In forest-based biorefineries, the value given to the materials that are produced could be partly determined by how long the carbon can be stored in these materials compared to other materials. This type of assessment would allow for better planning of biomass sources, production, manufacturing processes, and uses. This is particularly important in the cascading approach to biomass use[3] or in the transformation of biomass. In this approach, energy is needed in all stages, and its carbon footprint should be considered and reduced, if possible, for example though the use of renewable energy or energy-efficient technologies.

[3] The cascading use of biomass involves processing biomass into bioproducts that undergo single or multiple uses before disposal, extending the availability of biomass within a system. As a result, biomass-based value webs emerge, encompassing interconnected relationships within and between value chains (Gomez San Juan, Bogdanski and Dubois, 2019).

Chapter 2
Bioeconomy for a changing world: challenges and opportunities for agrifood systems

2.1 SCIENCE, TECHNOLOGY AND INNOVATION FOR BIOECONOMY

The Brazilian presidency of the G20 recognizes that bioeconomy is a "knowledge-based development model that includes new technologies as well as ancient technologies and traditional knowledge, such as the use and management of ecosystems and biodiversity species" (G20 Brazil, 2024).

Technology and innovation have the potential to resolve and minimize sustainability trade-offs. This is particularly true if both new and traditional technologies and knowledge are brought to the same level and support each other to achieve common objectives. This is underscored by the pervasive presence of science, technology and innovation across all bioeconomy strategies. Approximately one-third of the measures outlined in dedicated strategies are intricately linked to advancing technology and fostering innovation (FAO, 2024a).

Biotechnologies offer a wide array of options (e.g. biopesticides, biofertilizers, biostimulants, and bio-based and compostable plastics) for reducing the environmental impact of obsolete and polluting agricultural practices; improving the safety of agricultural work; producing healthier food; and regenerating degraded soils (Lokko *et al.*, 2018; Gomez San Juan, Harnett and Albinelli, 2022a). These options are in line with the 'One Health' approach.[4] It is also hoped that digitalization will enhance the operational efficiency of agrifood systems by improving water use efficiency, disease control, supply chain management, and reducing post-harvest food losses, and thereby reduce their environmental impact. For instance, advances in remote sensing technologies and their increasing role in precision agriculture can allow for the implementation of drought monitoring mechanisms (Alahacoon, Edirisinghe and Ranagalage, 2021). Digital solutions also have the potential to connect

[4] The One health joint plan of action (2022–2026) promotes the adoption of cross-cutting initiatives associated with systems thinking, advocacy, public-private partnerships, good governance, robust institutional and legal frameworks, and the valorisation of traditional knowledge of local and indigenous peoples, to build connections across the six action tracks (FAO, UNEP, WHO, and WOAH. 2022).

small-scale rural producers with consumers through online platforms for e-commerce and delivery services and marketing. Blockchain technology can improve traceability and certification schemes (Trendov, Varas and Zeng, 2019).

Indigenous knowledge and practices contribute to knowledge of biodiversity and *in situ* and *ex situ* conservation (Gomez San Juan, Harnett and Albinelli, 2022a). Indigenous knowledge systems also have great potential for communicating valuable lessons that have been learned over generations on how to achieve food security and diversified production while preserving ecosystems, cultures, and livelihoods. The synergies between indigenous knowledge systems and scientific activities need to be more widely recognized and integrated with the latest advances in life sciences and innovation (e.g. data analysis and DNA sequencing). Technological advances can also reduce food loss and waste by creating new types of foods, food ingredients and bioactive compounds. These developments can also generate other bio-based products (e.g. textiles), forest-based products that capture and storage carbon (FAO, 2023c), and materials that can regenerate soil (e.g. compost and biochar).

Research and innovation that improves the efficiency in the use of biological resources is at the centre of the bioeconomy. For instance, biorefineries extract maximum value from biomass throughout its whole life cycle and convert residues into feedstock for new resources. This approach can also be applied to biomass of marine origin (Verissimo *et al,* 2021). This approach generates products with added value, such as bioactive molecules and medicines, food ingredients, as well as compost and bioenergy (Annevelink *et al*, 2022). The debate over the potential competition between biomass for food, energy and bio-based products, and the impacts this competition will have on land use, has stimulated the development of innovative technologies for biomass conversion that do not require land (e.g. microbial hydrogen production, synthetic biology, precision fermentation). Innovations of this type will play a crucial role in the development of a sustainable bioeconomy.

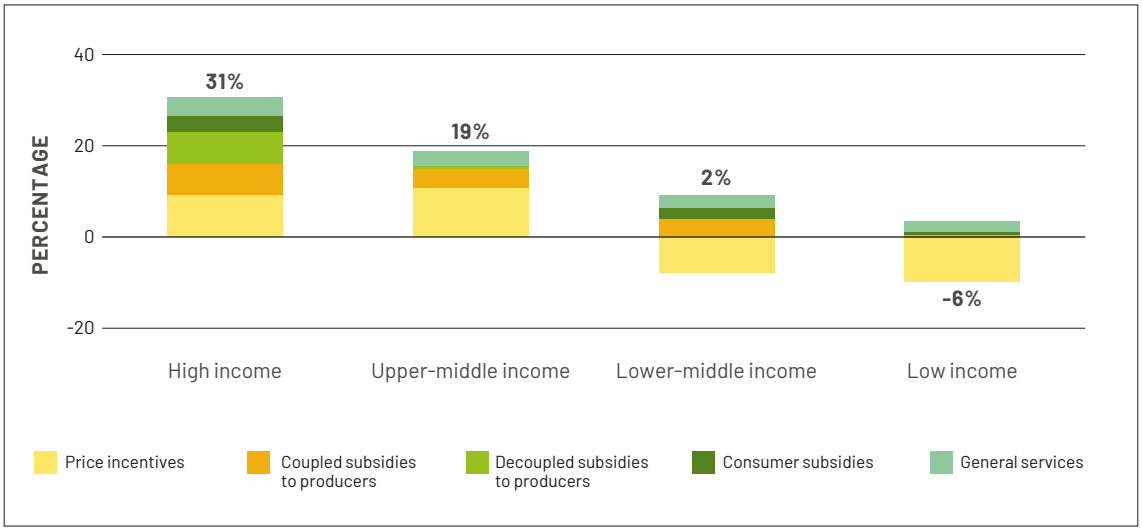
Innovative biological processes, such as those involving bacteria and enzymes, can offer environmentally friendly options on a case-by-case basis for breaking down waste; producing useful materials; and restoring ecosystems. These biological processes often have very high growth and efficiency rates. Microbial processes leverage the natural efficiency of living organisms that over millions of years of evolution and have produced specialized adaptations that can catalyse useful biological processes and produce valuable by-products.

Many biotechnological innovations are adaptable to different contexts and can be deployed in rural areas where infrastructure is scarce or where there is not sufficient biomass supply for large-scale industries (Fulford, 2015). One example is small-scale anaerobic digesters for treating livestock manure and organic waste. These digesters can convert organic waste streams to useful heat, electricity and organic fertilizers (O'Connor *et al.*, 2021).

Genetic engineering is being used to create pest-resistant crops and biofortified crops that can reduce the use of chemical pesticides, improve nutrition and promote better health outcomes in areas where diets depend on self-produced or locally procured staple crops. Hundreds of biofortified varieties of twelve staple crops have been released for planting in over 60 countries, with more than 86 million people in farming households eating biofortified foods (FAO *et al.*, 2023). However, the environmental and socio-economic context should be carefully considered before deploying these technologies, and the regulations governing them vary from country to country.

Currently, most agricultural research and development spending is concentrated in a few high-income countries. Often, the countries that have the most to gain from investments in research and development that could enable the bioeconomy take advantage of their rich biodiversity and drive the transformation of their agrifood systems to tackle poverty are the ones that are investing the least. In sub-Saharan Africa per capita investment in agriculture is five times lower than in high-income countries. Small-scale producers rely mostly on self-financing, as their access to formal credit is limited (FAO *et al.*, 2023). This situation threatens to trap many of the world's countries in technological dependency and constrain their access to innovations that suit their needs. Making science more inclusive and geographically diverse would ensure that transformative knowledge is widely disseminated (United Nations, 2023). Innovations must be accessible to the most vulnerable or the technological gap will grow (Box 3)(FAO, 2022b). This gap would penalize small-scale producers and rural communities, who are likely to be left behind due to initial investment costs and lack of training and education. Education and training are pre-requisites for translating innovations into development. Reliable infrastructure and access to affordable credit for agriculture are also crucial. Figure 2 shows how food and agriculture support as a share of production value is divided by income group and type of support.

Figure 2. **Support for food and agriculture as a share of production value, by income group and type of support (average 2013-2018)**



Source: **FAO.** 2023d. *The State of Food and Agriculture 2023 – Revealing the true cost of food to transform agrifood systems.* Rome. https://doi.org/10.4060/cc7724en

To lift 500 million people out of hunger and malnutrition by 2030, an average annual investment of about USD 27 billion is the required (von Braun *et al.*, 2024). This will include investments in agricultural research and development. Investments in research and development are the least costly in per capita terms, have a high benefit-cost ratio (10 and above), and offer tremendous potential for reducing hunger (Alston, Pardey and Rao, 2020). Other areas that will require increased investment include agricultural extension and information services, the expansion of small-scale irrigation, female literacy, and the scaling up of social protection.

Recommendation **3**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Scale up investments in science, technology, and innovation for agrifood systems in the bioeconomy

Commit to increasing investment and creating an enabling environment to improve access to finance and the transfer of technological innovations that can transform agrifood systems. Give particular attention to Small Island Developing States, low- and middle-income countries, and vulnerable groups. Support and encourage efforts by multilateral institutions and international financial institutions to develop dedicated criteria and indicators for bioeconomy investment, and mobilize additional resources to meet the demand of agrifood systems.

Box **3**

The FAO science and innovation strategy

FAO focuses on technological and innovative approaches to produce more with less. This includes creating greater options for mitigating water scarcity, land degradation, food loss, the overuse of inputs, and the erosion of biodiversity; reducing the cost of nutritious food, and food and agricultural prices in general; and lowering the risks of epidemics and pandemics. Innovative technologies are also promoted to increase transparency in transactions, create new earning opportunities, boost overall technical progress and promote social inclusion. Examples of FAO work include facilitating the voluntary sharing of knowledge and practices, transferring research and technology on mutually agreed terms, and ensuring equitable access to knowledge and technologies. FAO also works to improve access to investments and financial resources at the national, regional and international levels through a range of mechanism, including south-south cooperation and triangular cooperation. FAO activities aim at strengthening the cooperation in science, technology and innovation, and valorising traditional knowledge to bring sustainable practices to all. These activities, which are guided by inter-linked principles and aligned with 2030 Agenda, are closely connected to the sustainable development of the bioeconomy. FAO is committed to ensuring that science and innovation should be (i) rights-based and people-centered; (ii) gender-equal; (iii) evidence-based; (iv) needs-driven; (v) sustainability-aligned; (vi) risk-informed; and (vii) ethics-based.

2.2 SUSTAINABLE USE OF BIODIVERSITY FOR BIOECONOMY

Preserving biodiversity and sustainably using and regenerating genetic resources is important for a sustainable bioeconomy. It is also a global social and ethical obligation, especially towards Indigenous Peoples, who have deep cultural connections to specific ecosystems and landscapes (Gomez San Juan and Bogdanski, 2021; Gomez San Juan, Harnett and Albinelli, 2022a; UNEP, 2024).

The bioeconomy embraces different bio-based value chains and economic activities that depend on biodiversity and ecosystem services. The conservation, protection, sustainable use and regeneration of biodiversity and the maintenance of ecosystem health are essential components of successful bioeconomy strategies and policies. A well-developed sustainable bioeconomy contributes, directly or indirectly, towards achieving the SDGs associated with biodiversity: SDG 14 (Life below Water), and SDG 15 (Life on Land). There are multiple bioeconomy practices that have direct and indirect positive impacts on biodiversity. These practices address, often simultaneously, the five principal drivers of biodiversity loss: land- and sea-use change; the overexploitation of natural resources; pollution; invasive alien species; and climate change (IPBES, 2019). A sustainable bioeconomy protects biodiversity, while at the same time supporting global food security, climate protection, increased resiliency and the sustainable management of natural resources (Gomez San Juan, Harnett and Albinelli, 2022b).

Making efficient use of biomass, promoting circularity[5] and adopting approaches that seek to retain the value of the biomass as much as possible within the agrifood system, reduces pollution, increases efficiency in the use of other resources and provides many other environmental benefits. This, in turn, can address resource scarcity and reduce land-use change, which is the main factor that necessitates sustainability trade-offs (Gardossi *et al.*, 2023). Almost all countries have integrated these approaches into their dedicated bioeconomy strategies. The goal is to generate new raw materials without harming the environment, increasing greenhouse gas emissions, or depleting existing carbon stocks. Waste streams are kept to a minimum, and biological 'waste' becomes a resource with value instead of being discarded.

Sustainable bioeconomy practices related to afforestation and reforestation can reduce habitat loss and restore ecosystems. Science and innovation in the bioeconomy are also finding new ways of harnessing the potential of microorganisms and the diverse microbial environments in which they operate (microbiomes). Microbiomes perform essential functions for soils, crops, animals, forests, people, and ecosystems. Microbial-based strategies can restore degraded ecosystems, enhance biodiversity, and improve ecosystem services (Kendzior *et al.*, 2022).

Bioeconomy options can contribute to habitat protection and the restoration of degraded or polluted ecosystems, for instance through the application of biofertilizers and biopesticides. Bioeconomy products can also improve the soil and plant microbiomes, leading to a healthier environment. This has been highlighted in the Work Plan for the Sustainable Use and Conservation of Microorganisms

[5] While concepts of circular economy and bioeconomy share some important similarities – focus on sustainability by optimizing product design, material flows, and resource efficiency, emphasis on resource efficiency, and the addition of new functionalities to materials) – they also differ in their scope and innovation. Bioeconomy goes beyond the circular economy by aiming for more disruptive innovations such as social and high-tech innovations technologies like biobased 3D printing, biomimicry, and biomanufacturing, developing new solutions, services, and products that combine sustainability with increased consumer benefits and specific focus on adding value to biological resources and processes, including the conversion of bio-waste into useful products. Bioeconomy also offers opportunities for synergies between the two concepts (IACGB, 2020).

and Invertebrate Genetic Resources for Food and Agriculture (FAO, 2019). Bioremediation is the process of treating and detoxifying environmental contaminants in soil, water or other environments by taking advantage of natural biological processes using plants (phytoremediation), microbes (soil inoculation, biostimulation, bioaugmentation), fungi (mycoremediation) or even animals such as fish (biomanipulation). This process is used to restore polluted soils, wetlands and freshwater ecosystems. The bioeconomy maximizes the use of residual streams from agriculture, food processing, and forest-based industries, turning them into a range of products with added value. This reduces pollution and the amount of material sent in landfills and water streams, which are a serious threat for biodiversity and ecosystems.

The bioeconomy can also support biodiversity through the use of bio-based, biodegradable and compostable products that can provide a substitute for fossil fuel-based products. This reduces plastic pollution and soil contamination in agrifood systems. Innovations in bioscience, biotechnology, and bioinformatics can help in the collection, handling, storage, and supply of genetic resources and other biological materials. These materials are essential to increasing our knowledge of global biodiversity and for conserving this biodiversity *ex situ*. It is important that the benefits arising from the sustainable use and conservation of biodiversity and related traditional knowledge be shared fairly and equitably within the bioeconomy, particularly with Indigenous Peoples and local communities.

International agreements on biodiversity

There are many international agreements, legally binding instruments, declarations and action plans on biodiversity that are relevant for the bioeconomy. These agreements cover the sustainable use, conservation, and regeneration of biological diversity and ecosystems, and include measures to ensure biosafety and biosecurity and the fair and equitable access to genetic resources and benefit-sharing (CBD, 2024a). The role of the bioeconomy can play in achieving these biodiversity commitments has been garnering greater attention. As the bioeconomy both depends on biodiversity and will have an impact on it, it is crucial to align and integrate bioeconomy strategies with these international biodiversity instruments.

The recent adoption of the Kunming-Montreal Global Biodiversity Framework (GBF) was a significant milestone. The GBF outlines ambitious goals and targets to be achieved by 2030 and 2050. These goals and targets are aligned with the SDGs (CBD, 2024b; FAO, 2024b). This alignment makes multistakeholder and international cooperation essential (Box 4). The sustainable development of the bioeconomy can support the achievement of different GBF targets. The FAO Global Bioeconomy Dashboard, which analyses the links between bioeconomy strategies and national climate and biodiversity objectives, indicates that 454 actions included in national bioeconomy strategies are in line with several GBF targets (FAO, 2024a). These actions are related to:

- bioremediation that can help restore degraded terrestrial and aquatic ecosystems (Target 2);
- biosciences and innovation can enhance the *in situ* and *ex situ* conservation of biodiversity (Target 4);
- bioproducts that can help reduce soil and water pollution and emissions from fossil fuels (Target 7);
- the development of local value chains based on sustainable biological resources that can empower local and Indigenous Peoples by diversifying income opportunities (Target 9);
- bioprospecting and biosecurity regulations that can stimulate innovations in bioscience, biotechnology and bioinformatics and support access and benefit sharing (Target 13); and

- circular bioprocesses that generate more production with fewer resources, turn waste into valuable products, and when combined with measures to lower demand, can reduce waste and overconsumption (Target 16).

Biodiversity and climate action are also intrinsically connected. Practices that simultaneously improve biodiversity conservation and climate change mitigation and adaptation should be prioritized in the bioeconomy (e.g., agroecological practices, sustainable forest management, ecosystem restoration and others). The FAO's Aspirational Principles and Criteria for a Sustainable Bioeconomy emphasize that biodiversity conservation, climate change mitigation and adaptation should be pursued simultaneously in a sustainable bioeconomy. The FAO dashboard has mapped close to a thousand actions that have been prioritized by the national bioeconomy strategies of 21 countries and three regions (as of December 2023), and found that 503 of these actions are linked to the Intergovernmental Panel on Climate Change (IPCC) mitigation options and 335 are linked to IPCC adaptation options (FAO, 2024a).

In adopting the GBF, Parties to the Convention on Biological Diversity (CBD) have committed to setting national priorities targets that will be implemented through the development, or the updating, of their National Biodiversity Strategies and Action Plans (CBD, 2024c). According to the FAO Dashboard, some countries have already integrated bioeconomy into their biodiversity action plans[6], and are reporting on bioeconomy activities that benefit biodiversity in their national biodiversity reports[7] (FAO, 2024a).

The objective of the CBD is the conservation of biological diversity, the sustainable use of genetic resources, and the fair and equitable sharing of the benefits arising from the utilization of genetic resources. All of these objectives are key elements in the development of a sustainable bioeconomy. Under the CBD, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization provides a transparent framework for the fair sharing of benefits from genetic resources utilization, including traditional knowledge (CBD, 2024d). This is particularly important for the bioeconomy, and countries are increasingly integrating the measures into their bioeconomy strategies to combat biopiracy.

The safe handling of living modified organisms from biotechnology is regulated by the Cartagena Protocol. This safety framework is crucial for enabling sustainable practices within the bioeconomy; facilitating the integration of biotechnological advancements in agriculture and industry; and protecting natural ecosystems and people.

Digital sequence information on genetic resources is an important issue for the bioeconomy. In 2023, Parties to the CBD and the Nagoya Protocol agreed to establish a multilateral benefit-sharing mechanism for the use of digital sequence information. Provisions regarding digital sequence information are also included in the GBF (CBD, 2024e).

Almost all the bioeconomy-dedicated strategies reviewed by FAO contain provisions and mechanisms for the implementation of the CBD and the Nagoya and Cartagena Protocols. Most aim to ensure the sustainable use of biological resources. More than half seek to harness bioscience, biotechnology, and bioinformatics innovations to collect, handle, store and supply genetic resources and other biological materials. Almost half of the strategies reviewed highlight that the knowledge and benefits arising from biodiversity management should be equitably shared and accessible to all (Box 4).

[6] These countries are: Algeria, Denmark, Finland, Indonesia, Kingdom of the Netherlands, Pakistan, South Africa and Thailand.

[7] These countries are: Brazil, Canada, Finland, Haiti, Indonesia, Kingdom of the Netherlands, Peru, Portugal and Sweden.

Box 4

The International Treaty on Plant Genetic Resources for Food and Agriculture: Bioprospecting and Access and Benefit Sharing

Countries rely on each other for genetic resources for crops, livestock, fishing, aquaculture, and forestry to sustain their agrifood systems. To facilitate cooperation in this area, FAO established the Commission on Genetic Resources for Food and Agriculture. The Commission hosted the negotiations for the International Treaty on Plant Genetic Resources for Food and Agriculture to support sustainable agriculture and food security. The Treaty, which came into force in 2004, is of particular importance to sustainable bioeconomy development.

The Treaty is hosted by FAO and manages the Benefit-sharing Fund. The Fund supports projects that leverage plant genetic resources to safeguard food security and nutrition, improve rural livelihoods and support climate change adaptation. So far, the Fund has supported four project cycles with 80 projects funded around the world in collaboration with over 500 organizations. The primary beneficiaries are farmers in low- and middle-income countries who conserve and sustainably utilize plant genetic resources to support research and develop crop varieties that are more resilient, more productive and nutritious. Projects are divided in three domains:

- managing plant genetic diversity with farmer participation;
- strengthening local value chains; and
- sharing plant genetic resources, data and knowledge.

There are several projects in which non-wood forest products are managed by indigenous communities with valuable knowledge on their sustainable use and conservation.

2.3 BIOECONOMY FOR SUSTAINABLE DEVELOPMENT

Sustainability and the trade-offs related to the production and utilization of biological resources are the biggest challenge of the development of the bioeconomy. However, these challenges can become opportunities when the transition to a sustainable bioeconomy is undertaken in a holistic manner. This involves developing the bioeconomy as a cross-cutting framework for managing natural resources to reach national context-specific sustainability objectives. The bioeconomy framework needs to be supported by good governance mechanisms and adhere to well-defined sustainability principles and criteria. This approach will capture the complex interconnections between the economic, environmental, and social aspects of the bioeconomy, and help to strike a balance between the different objectives. It also involves leveraging and valorising existing resources more effectively; tapping into previously untapped resources (e.g. waste, residues, and by-products); and improving agricultural productivity. At the same time, care must be taken that these gains are equitably shared among disadvantaged and vulnerable stakeholders. Science, technology and innovation, the sustainable use of biodiversity, and the promotion of sustainable development are crucial elements for leveraging the potential of agrifood systems in the bioeconomy.

Recommendation **4**

Develop holistic, practical and transparent bioeconomy policies, strategies and plans

Bioeconomy policies, strategies, and plans should be tailored to national circumstances and capacities. At the same time, there needs to be policy coherence among the sustainable development frameworks and the goals of the multilateral environmental agreements of relevance to bioeconomy across different sectors at the local, national, regional, and international level. The use of transparent criteria and methodologies for monitoring and evaluating the sustainability of bioeconomy activities is essential.


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Agrifood systems will play a central role in the transition from a fossil-based economy to a bioeconomy, and their transformation has the potential to have significant positive impact on the lives of people. Approximately 60 percent of the world's population depend on agrifood systems for their livelihoods, including 1.2 billion rural people living in moderate to extreme poverty (FAO, 2022a).

The challenges facing global agrifood systems include meeting the nutritional needs of over 800 million people who are currently facing hunger and ensuring access to healthy diets for the 3.14 billion people (42 percent of the world's population) who are not assured of this access. Many of these people are severely impacted by natural disasters, climate change, and conflicts. Agrifood systems are central to ensuring livelihoods and food security, including providing opportunities for decent work and more options for generating income in rural areas (FAO, 2022a). It is estimated that the average incomes of the moderately poor working in agrifood systems must increase by a staggering 57 percent in low-income countries and 27 percent in lower-middle-income countries (FAO, 2023d). These increases are needed to ensure these workers can rise above the moderate poverty line and do not experience food insecurity and undernourishment. The bioeconomy can act as a powerful catalyst for more equitable economic development and social progress in all agrifood systems. It offers diversified livelihood opportunities that can reduce the vulnerability of rural communities.

The agriculture sector is responsible for four percent of the global GDP (FAO, 2023b). Small-scale producers, local communities and Indigenous Peoples own or manage nearly half of the world's forest and farm landscapes (4.35 billion ha) and generate an estimated gross annual income of up to USD 1.29 trillion (FAO, 2022c). These producers contribute significantly to broadening the earning potential for more impoverished social groups, both within and outside agrifood systems.

There is a growing emphasis in bioeconomy initiatives on the promotion of decentralized processing of biomass as a way to revitalize rural economies, reduce outmigration and generate employment alternatives (von Braun, 2014). Fossil feedstocks supply chains rely on capillary global chains for the delivery of low-cost oil and gas. Contrary, the early stages of biomass processing are better carried out in the regions where the biomass is produced. Intermediate products obtained from biomass may be shipped to large specialized industrial centres for further processing. Biomass processing is generally

more labour intensive and carried out on a smaller scale than fossil-based value chains. Therefore, ensuring that the later stages of value addition are done in the areas where biomass is produced is an option for creating green jobs in rural areas. The bioeconomy can also create opportunities to diversify rural livelihoods, which can further reduce vulnerability. For example, sustainable forest management practices, ecotourism, non-timber forest products, and the valorisation of agrifood residues and waste, can provide alternative sources of income that can help communities adapt to changing environmental conditions and economic challenges.

These innovations also contribute to strengthening resilience, especially in vulnerable rural communities (Wesseler and von Braun, 2017). By making use of new resources and building access to new markets, these actions generate additional sources of income and employment opportunities. In this way, the bioeconomy can stimulate entrepreneurship, create training and education opportunities, improve the quality of life of local people, and generate added value that has a positive impact in the areas where biomass is produced (Lokko *et al.*, 2018).

The sustainable use of land will be crucial to limit global warming to 1.5°C, protect biodiversity, prevent rural depopulation, and curb migration. Furthermore, ensuring adequate land rights and tenure security is crucial for the development of a sustainable bioeconomy. It must be underlined that land use and land-use change remain one of the major factors that contributes to sustainability trade-offs of bioeconomy (Meyfroidt *et al.*, 2022). Practices that optimize the use of biological resources and land and at the same time reduce trade-offs include using marginal land for non-food crops and adopting sustainable intensification practices that use the land for multiple purposes (e.g. combining food and non-food feedstocks) or for cultivating multipurpose crops (Gomez San Juan, Bogdanski and Dubois, 2019). Secure land tenure encourages investments in sustainable agricultural practices and helps in achieving food security and nutrition goals. In assessing the impacts of different land-use options for biomass production and consumption, policy makers and regulatory bodies need to pay attention to a range of socio-economic factors because value addition can deliver economic benefits, but also can have unwanted environmental and social impacts.

By increasing interactions between the agrifood systems with other socio-economic and environmental systems and sectors, the bioeconomy's transformative potential to support sustainable rural transformation. These cross-sectoral interactions add value to local biological resources, which creates processing and manufacturing opportunities in rural areas (Giampietro, 2019). The bioeconomy could have a positive impact on livelihoods, if the benefits of bioeconomy innovations, new value chains and increased sustainability are shared equally (Box 5).

Box 5

Regenerative bioeconomy for rural areas

The Bioeconomy Strategy of the East Africa Community and bioeconomy programmes in the region are an example of how the bioeconomy can offer integrated solutions to multi-sectoral needs in low- and middle-income countries. In these initiatives, a technology-driven approach is prioritized to improve food security and create new value chains and market opportunities for small-scale producers and small and medium-sized enterprises. Regional issues that are addressed include (i) modern bioprocessing to add value to primary production and agricultural residues; (ii) protein production systems based on insects or algae that replace resource-intensive livestock production; and (iii) the use of biopesticides, bio-fertilizers, growth-enhancing micro-organisms and biocontrol agents derived from organic and renewable resources to sustainably control pests and diseases.

The East African region aims to develop a bioeconomy that harnesses local capacities and biological resources. The goal is to generate economic growth by meeting the increasing market demand for novel food and feed; and respond to the pressure of plant and animal diseases and pests with locally produced bio-based products that are both clean and economically affordable to small-scale producers. Regional bioeconomy development promotes the diversification of agricultural practices, foster links with emerging sectors and businesses, builds public-private partnerships, and encourages sustainable public procurement practices.

Recent reports state that between 2020 and 2050, the population living in urban areas will increase from 53 percent to 70 percent (FAO, 2021a). Population dynamics have implications for agrifood systems because population growth, urbanization, and demand for agrifood products are closely linked. Urbanization transforms agrifood systems by reshaping consumer preferences and changing how, where and what food is produced, supplied and consumed. Current trends indicate that cities will consume around 90 billion tonnes of materials annually by 2050 compared to 40 billion tonnes annually in 2010 (IRP, 2018). Based on these figures, it is clear that cities should be given adequate consideration in any discussion about the development of the bioeconomy and any other major societal transformation (Yang and Yang, 2022). As urban areas become better connected to rural areas, producers may gain better access to agricultural inputs and services. This would improve productivity, which typically leads to increases in income. In the face of urbanization, agrifood systems should no longer be considered strictly from a rural perspective only. Rural and urban areas should be seen as integrated entities. The urban bioeconomy can contribute to more sustainable cities that benefit from emerging bioeconomic components such as urban farming, biowaste valorisation and sustainable infrastructure (Yang and Yang, 2022). Box 6 presents an example of a FAO project on urban bioeconomy and the win-win opportunities created by raising insects (FAO, 2024c).

Box 6

Urban bioeconomy in Abidjan

An innovative FAO project, BioDAF 'Circular Bioeconomy in Abidjan: From Food Waste to Fork', in Côte d'Ivoire provides an example of urban bioeconomy development. Abidjan has a population of over six million and faces the pressing need to dispose of about 2 500 tonnes of organic waste every day. Black soldier fly larvae (*Hermetia illucens*) are used to rapidly digest and decompose organic waste. The digested material is used as organic fertilizer in crop production. The mature larvae are a valuable source of protein for fish, poultry and pig farmers. An oil derived from the larvae promises to be useful to the pharmaceutical and cosmetic industries. The project, which was developed by FAO in collaboration with the Autonomous District of Abidjan and the Circular Economy Institute of Abidjan, creates employment opportunities, particularly for young people and women. It also links urban, peri-urban and rural areas by fostering sustainable innovation and creating new livelihoods.


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Recommendation 5

Promote the bioeconomy for rural-urban transformation

Promote inclusive and equitable bioeconomy development in rural and urban areas by supporting local bio-based value chains that valorise waste, residues, and by-products; decentralized biomass processing; and rural and urban entrepreneurship and innovation through policy incentives, technical assistance, training, and investment.

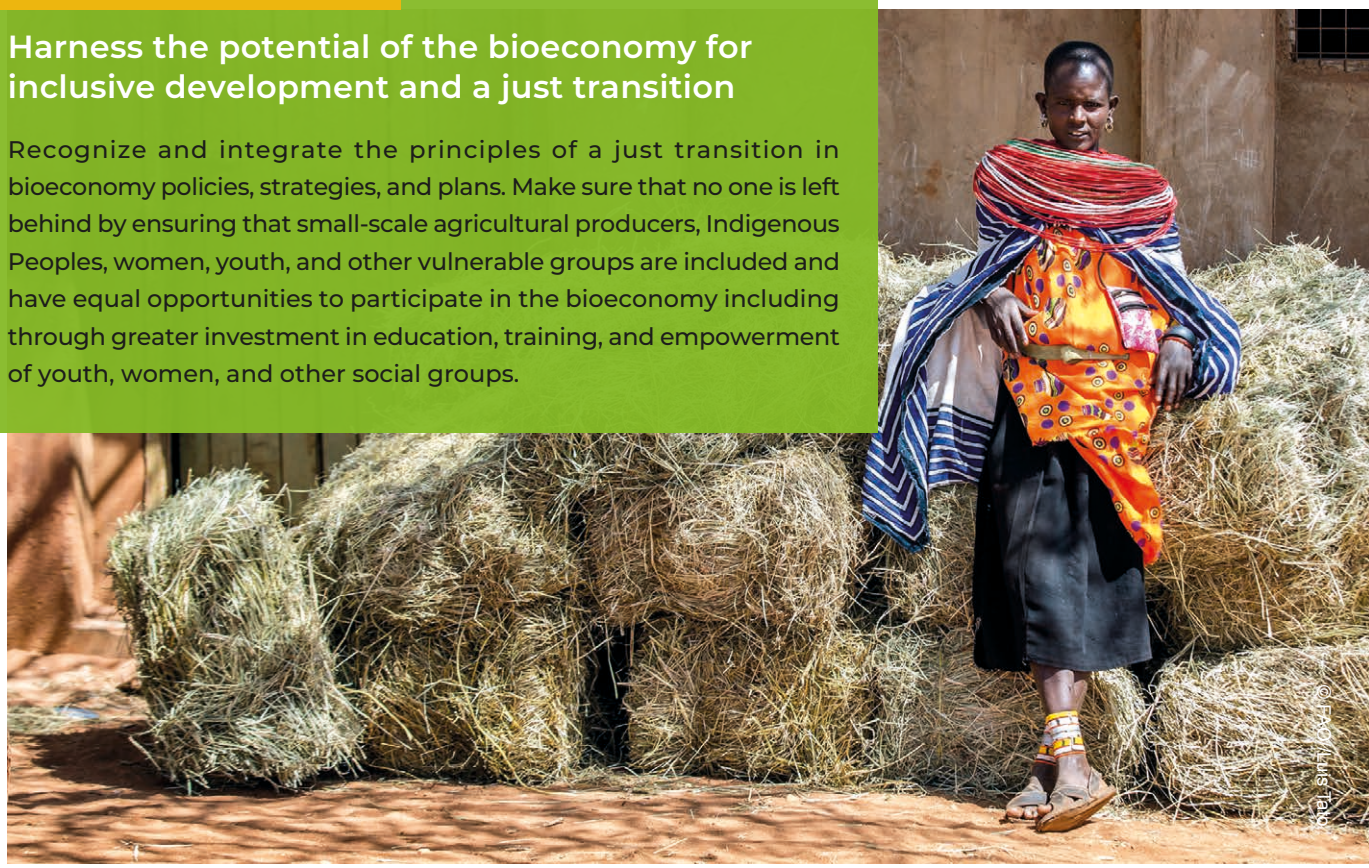
A whole-of-society approach is essential for governing a successful transition to a sustainable bioeconomy. There is concrete evidence of successful bioeconomy initiatives in which key stakeholders have included vulnerable groups, Indigenous Peoples, youth and women (e.g. ILO, 2023; Dietershagen and Bammann, 2023; OECD, 2020). Traditionally disadvantaged groups deserve legal recognition and meaningful participation in policy and investment interventions. In 2021, women represented 37.8 percent of all agricultural workers. However, the percentage is above 50 percent in 22 countries, most of them in Africa (FAO, 2023b). In every region of the world, statistical data show a greater prevalence of food insecurity among adult women compared to men along with other persistent gender inequalities. Bioeconomy initiatives can create opportunities for rural women to participate in decision-making processes and gain economic independence. In addition to economic aspects, bioeconomy work recognizes the traditional knowledge and expertise that women bring to bio-based processes (FAO, 2024d; FAO, 2024e).

Young people and civil society organizations are starting to be included in the global processes and platforms. However, they are still often excluded from the actual decision making. Young people should be empowered to contribute to sustainable bioeconomy development (Dietershagen and Bammann, 2023; EU, 2024). Their proactive involvement and leadership will be crucial to achieving the bioeconomy's full potential and tackling global issues in an all-encompassing and inclusive way.

Recommendation **6**

Harness the potential of the bioeconomy for inclusive development and a just transition

Recognize and integrate the principles of a just transition in bioeconomy policies, strategies, and plans. Make sure that no one is left behind by ensuring that small-scale agricultural producers, Indigenous Peoples, women, youth, and other vulnerable groups are included and have equal opportunities to participate in the bioeconomy including through greater investment in education, training, and empowerment of youth, women, and other social groups.



Approaches for informing consumers and creating demand for the bioeconomy products will play an important role to harness the potential of the bioeconomy. Biomass transport, delivery and storage are generally more costly than fossil feedstocks (Kircher, 2022). As a result, bio-products tend to be more expensive than fossil-based products. However, some studies have shown that the consumer willingness to pay a 'green premium' for certified bio-based products is increasing. Consumption and nutrition patterns resulting from the behavioural change of consumers are key factors that will shape the future of agrifood systems and the bioeconomy (FAO and WHO, 2019). Consumers are increasingly making complex choices about the sustainability, the nutritional content, and safety of the food they purchase. It is important for consumers to be aware that bio-based products have not only economic value but also a social, ethical value (FAO, 2023d). This can be supported by clearly defined standards, labels, and certifications to fight against illegality and counterfeiting. Internationally recognized procedures for setting the standards need to be established.

Forest-based livelihoods and forestry products and their contribution to the wider bioeconomy

Forests are one of the planet's most biologically rich ecosystems (CBD, 2008). They provide a range of ecosystem services that support local communities, agriculture, food security and nutrition (FAO, 2022d), and are of critical importance to various economic sectors. Sustainable forest management supports climate change adaptation and mitigation. This is achieved primarily through carbon storage in forest biomass, soil and wood products, and the substitution of wood products for more emission-intensive products (Nabuurs *et al.*, 2007; Verkerk *et al.*, 2022). Sustainable forest management also contributes to protecting biodiversity; curbing or reversing land degradation and desertification; and sustaining and improving livelihoods, food security and nutrition, cultural values and human health.

Forest-based value chains are essential elements of the bioeconomy and are at the forefront of an inclusive, low-carbon (FAO, 2023e; IUFRO, 2024). They provide sustainable and environmentally beneficial products that can serve as substitutes for non-renewable products and energy (FAO, 2021d). By supplying wood, fibre, energy, non-wood forest products, biochemicals, bioplastics and manufactured cellulose-based textiles, these value chains support the food and agricultural, construction, the pharmaceutical and bioenergy sectors (FAO, 2022c). The development of legal and sustainable forest-related value chains has the potential to underpin carbon-neutral economies and generate decent employment and livelihoods for millions of people (Lippe *et al.*, 2022; FAO and UNECE, 2019; Li *et al.*, 2022).

The increased use of wood products by 2050 may require the production of an additional 0.8 billion cubic metres of industrial roundwood. A greater area of planted forests will likely be needed if demand also increases for forest-based feedstock to produce more bio-based products (FAO, 2022e). Managing the production, utilization, conservation and restoration of forests and their associated value chains will require carefully balancing the interrelated objectives of social well-being, economic development, and environmental protection. This is a complex and challenging undertaking, as these elements are deeply interconnected (FAO, 2022c).

Sustainably meeting an increased demand for forest-based biomass will also require supportive policies, capacity building and investments at national, regional and global levels. Actions should strive to achieve four major goals: (i) an increased and sustainable supply of forest-based biomass through effective strategies that expand the area of naturally regenerated and planted forests, increase their productivity, and involve agroforestry and restoration activities; (ii) improved value addition, greater efficiency in manufacturing and energy flows, and the promotion of the cascading use of forest products, where applicable; (iii) a change in consumption patterns; and (iv) a transition to more sustainable economies. To achieve these goals, science-based innovation in forestry needs to be scaled up to increase the contribution of forestry to the bioeconomy.

Increasing forest-based production in naturally regenerated forests also demands political commitments to mitigate and adapt to climate change, and the development of comprehensive policies that balance carbon sequestration, biodiversity protection, and the production of forest products. The expansion of planted forests could be achieved by better integrating commercial timber production into forest and landscape restoration and agroforestry and tree crop plantation systems. While comprehensive data are lacking, these integrated systems such as agroforestry currently cover

Giant of Kauri Forest, Erromango Island, Vanuatu. Forests are a key part of the bioeconomy worldwide.

substantial areas, which could potentially be further increased as part of agricultural development, landscape restoration and establishing planted forests for multiple purposes.

At the same time, leveraging tree-growing initiatives within larger restoration activities can unlock the development of forest-based value chains. These value chains generate opportunities for local businesses that can provide seeds and planting materials that are genetically diverse and well-adapted to local conditions (Jalonen *et al.*, 2023). Engaging with forest-based industries as well as small-scale producers and communities active in commercial wood or non-wood forest product value chains can help expand the area of planted forests (Gomez San Juan, Bogdanski and Dubois, 2019).

Efficiency gains in forest-based production can be amplified through the cascading use of wood and other materials. Cascading use involves the efficient and sequential use of forest resources to maximize the overall utilization of the biomass. This includes residues and recycled materials that can be used for material applications before the final step in the 'cascade', which is often energy recovery. Adding value to products across the entire cascade can extend material lifespans, reduce the initial demand for materials, and enhance the sustainable use of forest products.

Currently, 27 to 34 percent of woodfuel extraction in tropical regions is unsustainable, and this unsustainable situation affects 275 million people (Bailis *et al.*, 2015). Closing this sustainability gap can be done by restoring degraded forests, establishing planted forests, improving the use of forest residues, and recovering post-consumer wood. Efficiency gains can be made by enhancing wood properties for different uses, improving processing, and increasing access to sustainable bioenergy sources. Meeting future woodfuel demand will require substantial improvements in resource allocation and a clear political vision. Scenarios for this demand vary widely, ranging from a 19-percent decrease to a 400-percent increase from 2020 to 2050 (FAO, 2022e).

A starfish (*Acanthaster planci*) in the Adang-Rawi Archipelago. Marine biological resources hold untapped opportunities to improve biodiversity.

Chapter 3

Enhancing global monitoring efforts: Aspirational Principles and Criteria for Sustainable Bioeconomy

The creation of an enabling environment is critical for the successful development of the bioeconomy. Ensuring sustainability will be a key objective for the global bioeconomy. However, currently there are no internationally agreed indicators, methods or metrics to measure the environmental sustainability of bioeconomy activities. This lack of agreement is partly because national bioeconomy strategy documents are very diverse (Gomez San Juan, 2024). Also, social and ethical issues (e.g. transparency, inclusiveness, the sharing of genetic resources, respect for the rights of Indigenous Peoples) are difficult to measure (FAO, 2021e). It is intended that the sustainable development of the bioeconomy will stimulate international trade, but the lack of internationally agreed criteria for assessing its sustainability makes it difficult to be assessed and monitored on an internationally comparable basis. Appendix 4 illustrates the diverse approaches countries have taken in establishing monitoring systems within their bioeconomy strategies.

In collaboration with the ISBWG, FAO has developed a set of 10 Aspirational Principles and 24 Criteria for Sustainable Bioeconomy (FAO, 2021e). The 10 principles and related criteria are used by FAO to provide support to countries (FAO, 2022g) address all 17 SDGs and their targets (Gomez San Juan, Bogdanski and Dubois, 2019).

The high-level principles (HLPs) proposed by the GIB cut across the three pillars of sustainability and could pave the way for harmonizing methodologies for both the public and private sectors. Assessing and measuring sustainability is a challenging task given the specificities of the various types of bioeconomies being implemented at national and regional levels (Gomez San Juan, 2024). Appendix 1 suggests a correlation between the SDGs and the proposed HLPs at the GIB meeting in Rio de Janeiro on 9-11 September. HLPs address most of the SDGs, albeit in a very general sense. Appendix 1 makes further links to the 24 Criteria of the FAO-ISBWG Aspirational Principles and Criteria that are used to assess bioeconomy strategies. Poverty (SDG 1), food security (SDG 2), health and well-being (SDG 3), education (SDG 4), sustainable economic growth (SDG 8), which includes also decent work and youth employment, are considered major priorities by most of the dedicated bioeconomy strategies as key to the sustainable implementation of the bioeconomy. More than half of the national bioeconomy strategies mention food security as a major priority. Similarly, urbanization (SDG 11) deserves more consideration given the increasing emphasis on the role of bioeconomy for urban development.

Fisherman catching Pirarucu fish in the Amazon.

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The FAO Aspirational Principles and Criteria were tested by reviewing case studies of bioeconomy interventions from around the word and across sectors (Gomez San Juan, Bogdanski and Dubois, 2019). FAO also tested the principles and criteria in three pilot countries (Malaysia, Namibia, and Uruguay) to review the policy landscape that supports or hinders the sustainability of the bioeconomy development strategies. It was concluded that a possible strategy for the easy monitoring of sustainability can be based on good practice reporting. FAO has also reviewed existing indicators at the territorial level, including bioeconomy-relevant SDG indicators, along with indicators at product and value chain levels, including criteria for standards, certification, and labels.

- Territorial indicators are designed to capture the impact of the bioeconomy strategy and the progress being made to implement it within a specific geographic area (e.g. country or a macro-region) or a specific ecosystem. These indicators can include data on the status of forests, agricultural productivity, and the overall economic contribution of bio-based sectors to the gross domestic product. The data are often derived from national statistics or international databases and provide a macro-level view of the bioeconomy's development and sustainability (Duveiller, Hooker and Cescatti, 2018 and 2021; Calicioglu and Bogdanski, 2021). There is a need for more bioeconomy-specific metrics, for example indicators that cross-over sectors and value chains. These metrics could involve good practices in mixed landscape indicators (Bracco *et al.*, 2019), integrated systems and biorefineries, or more broadly innovation and learning in land and biomass management.
- Value chain indicators focus on specific bio-based products or services and are used to assess their environmental, social, and economic impacts throughout their life cycle. This monitoring provides information on the sustainability of individual bio-based products, from production and processing to consumption and disposal. Value chain indicators can help identify hotspots of environmental impacts, opportunities for improving resource efficiency, and potential benefits for local communities and economies. FAO has developed a series of assessment tools and methodologies under the Sustainable Food Value Chains framework that can support the assessment, development, and monitoring of bio-based product value chains (FAO, 2024f).

Aerial view of Morovovonara and Makira Nature Park area.

FAO/David Mansell-Moullin

Another option is to undertake life cycle analyses (LCA) to evaluate the environmental footprint, social implications, and economic viability of bio-based products. This dual approach allows for a comprehensive assessment of the bioeconomy's sustainability and performance across different scales and sectors. A third level of assessment considers technological investment, which has been gaining greater attention by development banks and business developers.

- FAO has produced a compendium of 250 sources of good practices and policies that are potentially useful for translating bioeconomy strategies into sustainable actions, as part of the 'Towards Sustainable Bioeconomy Guidelines' project (Gomez San Juan and Bogdanski, 2021). The compendium analyses the extent to which the good practice can be recommended as a model. It considers the evidence of its impacts to determine whether it meets the five FAO criteria for good practice and policy: proven, sustainable, replicable, participatory and feasible. The compendium can be used by governments at different level in a country, and by private sector groups, investors and other stakeholders. It provides support in identifying good practices and policies that can help achieve the sustainability objectives of bioeconomy strategies; tracking progress in reaching these objectives; and learning from experience. The compendium follows all the elements of the bioeconomy definition, covering biological sciences and research, food production, advanced biomanufacturing, and end-of-life circularity practices.

The FAO Aspirational Principles and Criteria have been used to develop holistic monitoring frameworks that include indicators, metrics and tools that can be used to measure the extent to which strategies are being followed. These metrics, including bioeconomy-relevant SDG indicators, are used by countries and regions including Costa Rica (MICITT, 2024), the European Union (Giuntoli *et al.*, 2019) and Uruguay (Pozo *et al.*, 2023), and industries and other value chain actors. The development of these principles drew inspirations from the Committee on World Food Security (CFS) Responsible Investment in Agriculture and Food Systems (RAI Principles) (CFS, 2014) and FAO initiatives. Appendix 2 shows correlation of the most common 15 sustainability objectives of bioeconomy strategies worldwide identified by FAO with SDG targets. Appendix 3 shows the gaps in bioeconomy strategies against the 15 objectives.

The FAO Aspirational Principles and Criteria have also been used to map indicators and data sources in a compilation that is currently being updated (Bracco *et al.*, 2019). They have been referenced in the framework for the monitoring and evaluation of the bioeconomy that was launched by the European Commission in 2020 and implemented by the European Commission's Joint Research Centre (JRC).[8] The European Union Bioeconomy Monitoring System is publicly available through the European Commission's Knowledge Centre for Bioeconomy (Sanchez-Jerez, Raftoyannis and Rihimaki, 2023). Its interactive dashboard allows for tracking the progress the bioeconomy is making towards sustainability in the European Union and its Member States (EC, 2024).[9]

A joint FAO-JRC guidance note, developed under the mandate of the International Bioeconomy Forum, provides a step-by-step guide on how to set up a monitoring system for the bioeconomy at a country or regional level. The steps are grouped into three frameworks: (i) a conceptual framework, where all the elements of the monitoring system are defined; (ii) an implementation framework, where the conceptual framework is populated with indicators and data collection methodologies are selected; (ii) an assessment and communication framework.

Without proper assessment of the economic, environment and social sustainability of the bioeconomy, attempting a transition to a sustainable bioeconomy risks exacerbating challenges related to access to resources, environmental degradation, the distribution of knowledge, and land rights. Policymakers need to strengthen the alignment of bioeconomy initiatives with efforts to reduce these inequalities, enhance the effectiveness of these initiatives, and ensure they contribute to broader sustainability goals. Also, more work needs to be done to collect and analyze bioeconomy-related data, including scarce data on certain types of biomass use (e.g. biowaste, residues, by-products, microorganisms used in industry or soil microorganisms), and to involve marginalized groups in co-designing strategies, and promote inclusive options.

[8] The European Commission framework for monitoring and evaluating the bioeconomy consists of ten steps, with the selection, collection and compilation of indicators (currently 154) at its core, along with selection of reference values for each indicator to measure the progress of the bioeconomy towards its five strategic objectives. It covers environmental, social and economic dimensions of sustainability and is mapped to the SDGs.

[9] The European Union is supporting global coherence and cooperation through the actions undertaken by European Bioeconomy Policy Forum. All European Union member states work together with the JRC to develop suitable indicators that can be applied in a wider context.

Chapter 4
Way forward

The bioeconomy approach can support the transformation of agrifood systems so that they become more efficient, inclusive, resilient, and sustainable. However, it is critical that sustainability is assessed according to evidence-based principles, criteria and indicators to ensure that agrifood systems can meet the growing demand for biological resources without compromising the social, economic and environmental dimensions of sustainable development. The application of these principles and criteria should be defined by both specific national circumstances and capabilities, and a shared global vision for bioeconomy.

The development of the high-level principles for bioeconomy proposed by the GIB is a step forward for designing the bioeconomy governance landscape. The good bioeconomy practices already applied and tested can enrich this international dialogue and promote knowledge sharing.

A critical next step would be to forge agreement on the methodological approach to the assessment and monitoring of the sustainability of bioeconomy practices and actions. This would help to:

- ensure that the monitoring of the bioeconomy addresses all dimensions of sustainability and supports the management of potential synergies and trade-offs in line with the 2030 Agenda, SDGs and multilateral environmental agreements;
- foster mutual learning between countries and regions on innovative solutions to economic, social and environmental challenges, and encourage the sharing of good practices and policies;
- evaluate the transboundary effects of sustainable production and consumption of food, feed, bioproducts and bioenergy in a transparent way; and
- create common shared parameters to ground a common understanding of what a sustainable bioeconomy should look like.

Recommendation **7**

Establish globally accepted criteria for sustainable bioeconomy

Support the development of globally accepted sustainability criteria for the bioeconomy that are underpinned by empirical data, closely aligned with the SDGs.

A global comparative study of national bioeconomy strategies emphasizes the need for more intergovernmental cooperation and coordination to promote a sustainable bioeconomy, including an agreement on globally acknowledged standards for the bioeconomy (Proestou *et al.*, 2024). At the international level, uneven and unequal access to science, technologies, and innovation, varying institutional capacities, lacking legal, regulatory, and financial frameworks, and trade barriers compounded by a lack of engagement from international organizations are major impediments to advancing bioeconomy development worldwide (Dietz *et al.*, 2023).

The diversity of dedicated bioeconomy strategies, characterized by varying definitions and objectives across different countries and regions, while reflecting the varying national circumstances and capacities, further complicates the establishment of a cohesive global governance framework. Advancing bioeconomy at a global level requires coordination across countries, multiple sectors, and different levels of government, especially in federal systems. Currently, such coordination mechanisms are still emerging, and there is a recognized need to establish mechanisms that facilitate cooperation among the public, private, and third sectors at multiple levels (global, regional, national, and sub-national). Finally, the transboundary impacts and risks of the transition to the bioeconomy require international cooperation (von Braun and Birner, 2016).

The lack of a unified global platform for promoting and regulating the bioeconomy and the overlapping mandates of the existing global bioeconomy mechanisms remain important impediments to uniting the efforts of governments, the private sector, academia, and other actors within the bioeconomy to realize its transformative potential (IACGB, 2024). Such a unified global platform for a sustainable bioeconomy could facilitate the sharing of best practices, knowledge, and technology transfer, among other benefits, and address the interconnectedness of various sectors and regions. Without such a framework of global coordination, the bioeconomy's ability to contribute effectively to global sustainability goals may be compromised.

Recommendation **8**

Foster global cooperation for sustainable bioeconomy

The coordinated and synergistic actions needed to advance sustainable bioeconomy development would be bolstered by the establishment of a global multi-stakeholder platform with the participation of United Nation institutions. This platform could act as a catalyst for developing bioeconomy policies, strategies, and plans; building capacities and knowledge networks; and creating incentives at global, regional, national, and sub-national levels.

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APPENDICES

Appendix 1

Suggested correlation between the SDGs and the proposed HLPs at the GIB meeting in Rio de Janeiro on 9-11 September, and further links to the FAO-ISBWG Aspirational Principles and Criteria

Table A1.1. **Suggested correlation between the SDGs and the proposed HLPs at the GIB meeting in Rio de Janeiro on 9-11 September, and further links to the FAO-ISBWG Aspirational Principles and Criteria**

GIB High-Level Principles (HLPs)	SDG targets addressed	FAO criteria addressed
1. Integrate and promote sustainable development across its economic, social and environmental dimensions, contribute to a wide range of activities, eradicate hunger and poverty and improve health and well-being, whilst ensuring global food security and nutrition.	1.2 By 2030, reduce (…) poverty… 1.a Ensure significant mobilization of resources… 17.15 Respect each country's policy space…	3.1 Economic development is fostered
	2.1 By 2030, end hunger and ensure access by all people…	1.1 Food security and nutrition are supported
	2.2 By 2030, end all forms of malnutrition… 3.9 By 2030, reduce (…) illnesses from hazardous chemicals…	1.4 Food safety, disease prevention and human health are ensured
2. Be inclusive and equitable, uphold the rights of all persons, including Indigenous Peoples and members of local communities, promote gender equality and the participation of all stakeholders.	2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples…	3.1 Economic development is fostered
	5.5 Ensure women's full and effective participation and equal opportunities for leadership…	3.2 Inclusive economic growth is strengthened
3. Advance mitigation and adaptation efforts against global climate change, in line with applicable multilateral climate agreements.	13.2 Integrate climate change measures into national policies… 13.3 Improve education, awareness raising and human and institutional capacity on climate change mitigation, adaptation…	2.2 Climate change mitigation and adaptation are pursued
	7.2 By 2030, increase substantially the share of renewable energy… 12.1 Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns… 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters…	1.2. Sustainable intensification of biomass production is promoted 9.1. Consumption patterns of bioeconomy goods match sustainable supply levels of biomass 4.2 Resilience of biomass producers, rural communities and ecosystems is developed and/or strengthened 5.1 Resource efficiency, waste prevention and waste re-use along the whole bioeconomy value chain is improved 5.2 Food loss and waste is minimized and, when unavoidable, its biomass is re-used or recycled

GIB High-Level Principles (HLPs)	SDG targets addressed	FAO criteria addressed
4. Contribute to the conservation of biodiversity, the sustainable use of its components and the fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, subject to national laws and in line with applicable international agreements.	2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals... 15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity,... 15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources...	2.1 Biodiversity conservation is ensured
5. Advance sustainable consumption and production patterns and the efficient and circular use of natural resources, whilst promoting the restoration and regeneration of degraded areas and ecosystems.	15.3 By 2030, combat desertification, restore degraded land and soil... 15.5 Take urgent and significant action to reduce the degradation of natural habitats...	2.1 Biodiversity conservation is ensured 2.3 Water quality and quantity are maintained, and, enhanced 2.4 The degradation of land, soil, forests and marine environments is prevented, stopped or reversed
6. Be developed through safe, secure and responsible use of science, technology, innovation and traditional knowledge, with potential benefits, risks and impacts assessed scientifically.	9.5 Enhance scientific research, upgrade the technological capacities... 9.b Support domestic technology development, research and innovation... 17.6 Enhance North -South, South-South and triangular regional and international cooperation on and access to science, technology and innovation...	7.1 Existing knowledge is adequately valued and proven sound technologies are fostered 7.2 Knowledge generation and innovation are promoted
7. Benefit from robust and coherent policy frameworks that foster trade for bioeconomy products and services, market conditions, sustainable business models, decent jobs, local value creation and private sector and civil society participation.	2.b Correct and prevent trade restrictions and distortions in world agricultural markets... 17.10 Promote a universal, rules-based, open, non-discriminatory and equitable multilateral trading...	9.2 Demand-side and supply-side market mechanisms and policy coherence between supply and demand of food and non-food goods are enhanced
	8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people... 12.a Support developing countries to strengthen their scientific and technological capacity...	8.1 Local economies are not constrained but rather expanded through the trade of raw and processed biomass, and related technologies
8. Utilize transparent, comparable, measurable, inclusive, science-based and context-specific criteria and methodologies to assess their sustainability throughout the value chains.	12.6 Encourage companies (...) to adopt sustainable practices and to integrate sustainability (...) into their reporting... 17.19 By 2030, build on existing initiatives to develop measurements of progress...	6.3 Appropriate risk assessment and management, monitoring and accountability systems are put in place and implemented
9. Be fostered by international collaboration and cooperation that addresses global challenges, leverages complementary strengths, innovation and entrepreneurship and promotes financing, capacity building and sharing of best practices.	17.7 Promote the development, transfer, dissemination and diffusion of environmentally sound technologies... 17.9 Enhance international support for implementing effective... 17.16 Enhance the Global Partnership for Sustainable Development, complemented by multi-stakeholder partnerships...	10.1 Cooperation, collaboration and sharing of resources, skills and technologies are enhanced when and where appropriate
10. Be based on country-specific approaches and implemented in line with national priorities and regional and local circumstances.	11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas...	3.3 Resilience of the rural and urban economy is enhanced
	1.b Create sound policy frameworks... 16.7 Ensure responsive, inclusive, participatory and representative decision making...	6.1 Policies, regulations and institutional set up relevant to bioeconomy sectors are adequately harmonized

Source: Prepared by the authors.

Appendix 2

Common sustainability objectives identified in bioeconomy strategies and initiatives and related SDGs targets

Table A2.1. Common sustainability objectives identified in bioeconomy strategies and initiatives and related SDGs targets

SOCIAL					
To safeguard food security					
 Target 2.4 Target 2.a	 Target 3.4	 Target 12.3			
To support vulnerable stakeholders who act as guardians of natural resources, including low-income communities, smallholder agricultural producers and indigenous peoples					
 Target 1.3	 Target 15.6 Target 15.9	 Target 10.1			
To support research, development and innovation and put it into practice to accelerate the deployment of sustainable bioeconomy					
 Target 3.b	 Target 4.4 Target 4.b	 Target 9.5 Target 9.b	 Target 17.6	 Target 2.5	 Target 14.a
To promote sustainable consumption and raise the awareness and acceptance among consumers and manufacturers about the goods and services provided by the bioeconomy					
 Target 3.4	 Target 8.4	 Target 12.1 Target 12.7	 Target 13.3	 Target 17.14	

ECONOMIC

To increase profitability by adding value to biomass

Target 8.2

Target 9.b

Target 2.3

To create and secure employment through in situ value addition and enhance rural and urban economic resilience

Target 5.a

Target 8.5

Target 14.2

Target 15.9

To promote actions that contribute to the revitalization and development of rural areas

Target 7.b

Target 11.a

Target 2.a

To establish local fair and equitable value chains or webs by increasing inclusiveness and information flows

Target 10.3

Target 17.11
Target 17.17

ENVIRONMENTAL

To substitute fossil-based or unsustainably sourced products with sustainable bioproducts

Target 12.6
Target 12.c

Target 7.2

To incentivize the sustainable and efficient use of biological resources while protecting biodiversity, water and the soil

Target 2.5

Target 12.2
Target 12.c

Target 14.1
Target 14.4

Target 15.2
Target 15.3
Target 15.5
Target 15.6

To mitigate and adapt to the effects of climate change and reduce environmental pollution

Target 13.2

Target 12.4

Target 1.5

Target 3.9

Target 11.6

To move towards a more circular bioeconomy

Target 6.3
Target 6.4

Target 9.4

Target 11.6

Target 12.3
Target 12.4
Target 12.5

Target 13.1

GOVERNANCE

To promote synergies and reduce trade-offs between biomass uses while meeting the growing demand for food and non-food goods

Target 8.3

Target 16.7

Target 17.14

Target 1.b

To promote a transparent monitoring system for bioeconomy development and compliance with national and/ or international sustainability targets

Target 12.6
Target 12.b

Target 16.6

Target 17.19

To position the country as an international leader in the bioeconomy and improve its global competitiveness in trade and research

Target 10.6

Target 17.7
Target 17.9
Target 17.16

Target 12.8
Target 12.a

Source: prepared by the authors, based on **Gomez San Juan, M. & Bogdanski, A**. 2021. *How to mainstream sustainability and circularity into the bioeconomy. A compendium of bioeconomy good practices and policies*. Rome, FAO. www.fao.org/3/cb5798en/cb5798en.pdf

Appendix 3

How common sustainability objectives are addressed by bioeconomy strategies

Relationship between 15 major sustainability objectives that drive the development of bioeconomy in national and regional strategies and initiatives. These objectives encompass social, economic, and environmental dimensions, underpinned by governance arrangements (Gomez San Juan, and Bogdanski, 2021).

Table A3.1. **Shared sustainability objectives and how they are covered by national and regional bioeconomy dedicated strategies**

SOCIAL				
	To safeguard food security	To support vulnerable stakeholders who act as guardians of natural resources, including low-income communities, smallholder agricultural producers and indigenous peoples	To support research, development and innovation and put it into practice to accelerate the deployment of sustainable bioeconomy	To promote sustainable consumption and raise the awareness and acceptance among consumers and manufacturers about the goods and services provided by the bioeconomy
National bioeconomy dedicated strategies				
Austria – Bioeconomy: A Strategy for Austria	✓	Limited	✓	✓
Brazil – Estratégia Nacional de Bioeconomia	✓	✓	✓	✓
China – 14th Five-Year Plan bio-economy development plan	✓	✗	✓	Limited
Colombia – Bioeconomia: Para una Colombia Potencia viva y diversa: Hacia una sociedad impulsada por el Conocimiento	Limited	Limited	✓	✓
Costa Rica – National Bioeconomy Strategy: Costa Rica 2020-2030	Limited	✓	✓	Limited
Estonia – Circular Bioeconomy Roadmap for Estonia	✓	✗	✓	Limited
Finland – The Finnish Bioeconomy Strategy – Sustainably towards higher value added	Limited	✗	✓	Limited
France – A bioeconomy strategy for France	✓	Limited	✓	Limited
Germany – National Bioeconomy Strategy	✓	Limited	✓	✓

SOCIAL				
	To safeguard food security	**To support vulnerable stakeholders who act as guardians of natural resources, including low-income communities, smallholder agricultural producers and indigenous peoples**	**To support research, development and innovation and put it into practice to accelerate the deployment of sustainable bioeconomy**	**To promote sustainable consumption and raise the awareness and acceptance among consumers and manufacturers about the goods and services provided by the bioeconomy**
Ireland – National Policy Statement on the Bioeconomy	✓	Limited	✓	✓
Italy – La Bioeconomia in Italia	✓	Limited	✓	Limited
Japan – Bio-Strategy 2020	✓	✗	✓	Limited
Latvia – Latvian Bioeconomy Strategy 2030	Limited	✓	✓	✓
Malaysia – National Biotechnology Policy 2.0 – Towards a Bio-Innovative Society (2022 - 2030)	✓	Limited	✓	✗
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	✓
Netherlands (Kingdom of the) – The position of the bioeconomy in the Netherlands	Limited	✗	✓	Limited
Norway – Familiar resources: undreamt of possibilities – The Government's Bioeconomy Strategy	Limited	✗	✓	Limited
Portugal – Plano de Ação Para a Bioeconomia Sustentável – Horizonte 2025	✓	✓	✓	✓
South Africa – The bio-economy strategy	✓	Limited	✓	Limited
Spain – The Spanish Bioeconomy Strategy – 2030 Horizon	Limited	✓	✓	✓
Thailand – Bio-circular-green economy – action plan 2021-2027	✗	✓	✓	Limited
United States of America – Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy	Limited	Limited	✓	✗
Regional bioeconomy dedicated strategies				
European Union Bioeconomy Strategy	✓	✓	✓	✓
Nordic Bioeconomy Programme	✓	✓	✓	✓
The East African Community Bioeconomy Strategy	✓	✓	✓	✗

ECONOMIC				
	To increase profitability by adding value to biomass	**To create and secure employment through in situ value addition and enhance rural and urban economic resilience**	**To promote actions that contribute to the revitalization and development of rural areas**	**To establish local fair and equitable value chains or webs by increasing inclusiveness and information flows**
National bioeconomy dedicated strategies				
Austria – Bioeconomy: A Strategy for Austria	✓	✓	✓	Limited
Brazil – Estratégia Nacional de Bioeconomia	✓	✓	✓	✓
China – 14th Five-Year Plan bio-economy development plan	✓	✗	✓	✗
Colombia – Bioeconomia: Para una Colombia Potencia viva y diversa: Hacia una sociedad impulsada por el Conocimiento	✓	Limited	Limited	Limited
Costa Rica – National Bioeconomy Strategy: Costa Rica 2020-2030	✓	✓	✓	Limited
Estonia – Circular Bioeconomy Roadmap for Estonia	✓	✗	✗	✗
Finland – The Finnish Bioeconomy Strategy – Sustainably towards higher value added	✓	✓	Limited	Limited
France – A bioeconomy strategy for France	✓	✓	Limited	Limited
Germany – National Bioeconomy Strategy	Limited	✓	✓	✓
Ireland – National Policy Statement on the Bioeconomy	Limited	✓	✓	Limited
Italy – La Bioeconomia in Italia	✓	✓	✓	✓
Japan – Bio-Strategy 2020	Limited	Limited	Limited	✗
Latvia – Latvian Bioeconomy Strategy 2030	✓	✓	✓	Limited
Malaysia – National Biotechnology Policy 2.0 – Towards a Bio-Innovative Society (2022 - 2030)	✓	Limited	Limited	✗
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	✓

ECONOMIC				
	To increase profitability by adding value to biomass	**To create and secure employment through in situ value addition and enhance rural and urban economic resilience**	**To promote actions that contribute to the revitalization and development of rural areas**	**To establish local fair and equitable value chains or webs by increasing inclusiveness and information flows**
Netherlands (Kingdom of the) – The position of the bioeconomy in the Netherlands	Limited	Limited	✓	Limited
Norway – Familiar resources: undreamt of possibilities – The Government's Bioeconomy Strategy	✓	Limited	×	Limited
Portugal – Plano de Ação Para a Bioeconomia Sustentável – Horizonte 2025	✓	✓	✓	✓
South Africa – The bio-economy strategy	✓	Limited	Limited	×
Spain – The Spanish Bioeconomy Strategy – 2030 Horizon	✓	✓	✓	Limited
Thailand – Bio-circular-green economy – action plan 2021-2027	✓	✓	✓	×
United States of America – Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy	Limited	×	×	×
Regional bioeconomy dedicated strategies				
European Union Bioeconomy Strategy	✓	✓	✓	✓
Nordic Bioeconomy Programme	✓	✓	✓	✓
The East African Community Bioeconomy Strategy	✓	✓	✓	✓

ENVIRONMENTAL				
	To substitute fossil-based or unsustainably sourced products with sustainable bioproducts	**To incentivize the sustainable and efficient use of biological resources while protecting biodiversity, water and the soil**	**To mitigate and adapt to the effects of climate change and reduce environmental pollution**	**To move towards a more circular bioeconomy**
National bioeconomy dedicated strategies				
Austria – Bioeconomy: A Strategy for Austria	✓	✓	✓	✓
Brazil – Estratégia Nacional de Bioeconomia	✓	✓	✓	✗
China – 14th Five-Year Plan bio-economy development plan	Limited	✓	✓	Limited
Colombia – Bioeconomia: Para una Colombia Potencia viva y diversa: Hacia una sociedad impulsada por el Conocimiento	✓	✓	✓	Limited
Costa Rica – National Bioeconomy Strategy: Costa Rica 2020-2030	✓	✓	✓	✓
Estonia – Circular Bioeconomy Roadmap for Estonia	✓	✓	✓	✓
Finland – The Finnish Bioeconomy Strategy – Sustainably towards higher value added	✓	✓	✓	✓
France – A bioeconomy strategy for France	✓	✓	✓	✓
Germany – National Bioeconomy Strategy	✓	✓	✓	✓
Ireland – National Policy Statement on the Bioeconomy	✓	✓	✓	✓
Italy – La Bioeconomia in Italia	Limited	✓	✓	✓
Japan – Bio-Strategy 2020	✓	✓	✓	✓
Latvia – Latvian Bioeconomy Strategy 2030	✓	✓	✓	Limited
Malaysia – National Biotechnology Policy 2.0 – Towards a Bio-Innovative Society (2022 - 2030)	Limited	✓	✗	✓
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	Limited

ENVIRONMENTAL				
	To substitute fossil-based or unsustainably sourced products with sustainable bioproducts	**To incentivize the sustainable and efficient use of biological resources while protecting biodiversity, water and the soil**	**To mitigate and adapt to the effects of climate change and reduce environmental pollution**	**To move towards a more circular bioeconomy**
Netherlands (Kingdom of the) – The position of the bioeconomy in the Netherlands	Limited	✓	✓	✓
Norway – Familiar resources: undreamt of possibilities – The Government's Bioeconomy Strategy	✓	✓	✓	Limited
Portugal – Plano de Ação Para a Bioeconomia Sustentável – Horizonte 2025	✓	✓	✓	✓
South Africa – The bio-economy strategy	Limited	Limited	✓	Limited
Spain – The Spanish Bioeconomy Strategy – 2030 Horizon	Limited	✓	✓	Limited
Thailand – Bio-circular-green economy – action plan 2021-2027	Limited	✓	Limited	✓
United States of America – Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy	✗	✗	Limited	✗
Regional bioeconomy dedicated strategies				
European Union Bioeconomy Strategy	✓	✓	✓	✓
Nordic Bioeconomy Programme	✓	✓	✓	✓
The East African Community Bioeconomy Strategy	✓	✓	✓	✓

	GOVERNANCE			STI
	To promote synergies and reduce trade-offs between biomass uses while meeting the growing demand for food and non-food goods	To promote a transparent monitoring system for bioeconomy development and compliance with national and/ or international sustainability targets	To position the country as an international leader in the bioeconomy and improve its global competitiveness in trade and research	Science, Technology and Innovation
National bioeconomy dedicated strategies				
Austria – Bioeconomy: A Strategy for Austria	Limited	✓	✓	✓
Brazil – Estratégia Nacional de Bioeconomia	Limited	✓	✓	✓
China – 14th Five-Year Plan bio-economy development plan	✗	✗	✓	✓
Colombia – Bioeconomia: Para una Colombia Potencia viva y diversa: Hacia una sociedad impulsada por el Conocimiento	✗	✗	✓	✓
Costa Rica – National Bioeconomy Strategy: Costa Rica 2020-2030	✗	✓	✓	✓
Estonia – Circular Bioeconomy Roadmap for Estonia	Limited	✗	✓	✓
Finland – The Finnish Bioeconomy Strategy – Sustainably towards higher value added	Limited	✓	✗	✓
France – A bioeconomy strategy for France	Limited	✓	✗	✓
Germany – National Bioeconomy Strategy	Limited	✓	✓	✓
Ireland – National Policy Statement on the Bioeconomy	Limited	✓	✓	✓
Italy – La Bioeconomia in Italia	✗	✓	✗	✓
Japan – Bio-Strategy 2020	✗	✓	Limited	✓
Latvia – Latvian Bioeconomy Strategy 2030	Limited	✗	✓	✓
Malaysia – National Biotechnology Policy 2.0 – Towards a Bio-Innovative Society (2022 - 2030)	✗	✓	✓	✓
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	✓

	GOVERNANCE			STI
	To promote synergies and reduce trade-offs between biomass uses while meeting the growing demand for food and non-food goods	**To promote a transparent monitoring system for bioeconomy development and compliance with national and/ or international sustainability targets**	**To position the country as an international leader in the bioeconomy and improve its global competitiveness in trade and research**	**Science, Technology and Innovation**
Netherlands (Kingdom of the) – The position of the bioeconomy in the Netherlands	Limited	✗	Limited	✓
Norway – Familiar resources: undreamt of possibilities – The Government's Bioeconomy Strategy	Limited	✗	Limited	✓
Portugal – Plano de Ação Para a Bioeconomia Sustentável – Horizonte 2025	Limited	✓	Limited	✓
South Africa – The bio-economy strategy	✗	✓	✓	✓
Spain – The Spanish Bioeconomy Strategy – 2030 Horizon	✗	✓	✓	✓
Thailand – Bio-circular-green economy – action plan 2021-2027	✗	✓	✓	✓
United States of America – Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy	✗	✓	✓	✓
Regional bioeconomy dedicated strategies				
European Union Bioeconomy Strategy	✓	✓	✓	✓
Nordic Bioeconomy Programme	✗	✗	✓	✓
The East African Community Bioeconomy Strategy	✗	✓	✓	✓

Source: prepared by the authors, based on **FAO.** 2024a. *Dashboard on bioeconomy strategies and related actions for sustainable development*. Rome. [Cited 21 January 2024]. www.fao.org/in-action/sustainable-and-circular-bioeconomy/dashboard/en/

Appendix 4

Examples of bioeconomy strategies and action plans with monitoring frameworks and examples of monitoring methods and indicators

Austria: A scientific monitoring group was formed to assure the quality of the strategy development process and carry out studies on sustainability and other issues. There are also flagship projects used as proxies for the advancement of the strategy. (Austria, 2019).

Brazil: The strategy mandates the creation of indicators within the National Bioeconomy Development Plan. Also, the Ministry of Environment and Climate Change is in charge of a National System of Information and Knowledge on the Bioeconomy, for collecting, processing and storing information on the performance of the bioeconomy. (Brazil, 2024). The sub-national bioeconomy strategy of Para State links its result-based indicators to the objectives and actions as well as to the monitoring of the State Policy on Climate Change, among others. (State of Para, 2022).

Costa Rica: A bioeconomy observatory has been set up. Monitoring efforts are based on international criteria to demonstrate the alignment of the national strategy with multilateral agreements and international initiatives. (Costa Rica, 2020).

Finland: The revised strategy focuses on measuring value addition through circularity. It has also adopted the European Union bioeconomy strategy sustainability indicators. The Ministry of Economic Affairs and Employment is responsible for implementing the monitoring system. Finland monitors the main sectors (food, wood products, pulp and paper, bioenergy, bio-construction sectors, water, and nature tourism, recreation, recreational fishing, and hunting) with five economic indicators: output, value-added, investments, employment, and exports of bioeconomy goods. (Finland, 2022).

Germany: The monitoring of the bioeconomy strategy is based on three pillars that form the scientific basis for modelling sustainability on a national and international level: environmental indicators (e.g. biomass flows), economic indicators (e.g. value added, innovation and potential barriers) and social indicators (e.g. to delineate the impact boundaries of bioeconomy). (Germany, 2020).

Ireland: To translate the national vision for the bioeconomy into action, the Irish strategy adheres to four high-level principles: the sustainability principle, the cascading principle, the precautionary principle and the food-first principle. The High-Level Bioeconomy Implementation and Development Group is responsible for monitoring, annual reporting, and determining if revisions to the strategy are needed. (Ireland, 2023).

Italy: The strategy includes indicators for five topics; food security (e.g. change in food price volatility); sustainable natural resources management (e.g. change in land use intensity); reductions in dependence on non-renewable resources (e.g. energy intensity of the economy); climate change (e.g. changes in greenhouse gas emissions); and economic growth (e.g. job creation in skilled labour). (Italy, 2019).

Japan: The Japanese strategy has several targets by 2030 and related indicators for their monitoring. They cover five areas, namely investments in biomanufacturing including of bioplastics; sustainable primary production through smart technologies and environmental conservation; wood in construction; regenerative medicine products developed; and healthcare. (Japan, 2024).

Malaysia: Targets are continuously monitored through key performance indicators. For instance, the Malaysian Bioeconomy Contribution Index is used to monitor bioeconomy's economic performance. It is a composite index with five economic parameters: bioeconomy value-added, bio-based exports, bioeconomy investments, bioeconomy employment, and productivity performance. The strategy includes a system for automatic monitoring and evaluation using an analysis of blockchain data and artificial intelligence. (Malaysia, 2021).

Namibia: The strategy includes a comprehensive monitoring and evaluation framework for the bioeconomy, with short, medium and long-term measurements, and a list of indicators for each objective and target area of the strategy. Performance indicators are related to biomass production and processing in agrifood systems, the biomaterial and bioenergy used, as well as inputs, outputs, outcomes, and the impact of the biomass-based services in logistics, transport, retail, research, and tourism. (Namibia, 2024).

Portugal: Along with developing a monitoring system, the action plan includes the creation of result and performance indicators for the introduction of innovative financial incentives that can support the bioindustry, the elimination of obsolete fees, and the creation of mandatory evaluations of the effectiveness of existing rates. (Portugal, 2021).

South Africa: The national strategy includes a broad range of indicators, including government support for bio-based research and development; the number of bioeconomy-related publications; the amount of funding for supporting start-ups or new bio-based industries; the number of patents awarded; the number of bio-innovation firms established; the number of products available commercially; the trade balance of high-technology manufacturing goods; and multinational bioeconomy corporations that are operating local facilities. (South Africa, 2013).

Spain: A monitoring group has been created under an interministerial council, which includes representatives from different ministries and regions. The strategy considers two types of statistical and sustainability indicators at two different levels. The indicators measure the public and private investment in the bioeconomy and the number of activities being carried out. Also, they are used to evaluate the economic importance of the sectors associated with the efficient use of biomass and biological resources in four areas: final production, added value, employment, and exports. (Spain, 2016).

Thailand: As part of the strategy to implement the bio-circular-green economy model (BCG), outputs, outcomes and impact are monitored and evaluated through the Electronic Monitoring and Evaluation System of National Strategy and Country Reform (eMENSCR), which is administered by the Office of the National Economic and Social Development Council. (Thailand, 2022).

United States of America: The government has assessed, among other metrics, the feasibility, scope, and costs of developing a national measurement of the economic contributions of the bioeconomy, including through a satellite account for the bioeconomy as assessed by the U.S. Bureau of Economic Analysis (BEA)'s report "Developing a National Measure of the Economic Contributions of the Bioeconomy". (United States of America, 2022).

References for Appendix 4 - Examples of bioeconomy strategies and action plans with monitoring frameworks and examples of monitoring methods and indicators

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This paper has been prepared by FAO to inform the current discussions on bioeconomy including in the G20 Initiative on Bioeconomy (GIB). It focuses specifically on how bioeconomy can ensure food security and nutrition and, at the same time, on the need to transform agrifood systems to advance the sustainable development of the bioeconomy.

Global coordination and cooperation are an integral part of sustainable bioeconomy development. There is a need to implement agreed principles, criteria and monitoring systems that jointly address all dimensions of sustainability, to balance the trade-offs that can lead to the unsustainable implementation of the bioeconomy.

Multilateral institutions have an important role to play in tailoring these sustainable bioeconomy tools and guidelines in different contexts globally, while providing a neutral platform where all countries and stakeholders have a central role in shaping the future bioeconomy.

In this context the paper also contributes to the discussions around a set of High-Level Principles on Bioeconomy at the GIB. It presents an overview of FAO's work on bioeconomy, resources and networks, and provides lessons learned and recommendations for both G20 Members and globally.

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ISBN 978-92-5-139032-0
9 789251 390320
CD1976EN/1/09.24