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Bioeconomy for sustainable food and agriculture

A global stocktaking study

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Preface

Over the past 50 years, the use of material resources has surged dramatically, accompanied by a near doubling in the absolute extraction of biomass.[1] The projected 60 percent rise in biomass demand for food, energy, housing and other materials by 2060 underscores the urgent need for a transformative shift towards using biological resources sustainably.

A well-developed sustainable bioeconomy offers an approach for managing the differing needs for biomass considering environmental, social, and economic sustainability objectives, and protecting ecosystems that are rich in biodiversity and sequester carbon. By addressing global environmental challenges, the bioeconomy contributes to sustainable development. Over the last decade, the Food and Agriculture Organization of the United Nations (FAO) has played a pivotal role in guiding the global development of sustainable bioeconomy policies and practices. Bioeconomy for sustainable food and agriculture is one of FAO's Programme Priority Areas in the FAO Strategic Framework 2022-31. It reveals FAO and its Members' recognition of the need for a sustainable and innovative transformation of agrifood systems. Agrifood systems must meet the growing global demand for essential resources, without polluting and depleting natural resources and negatively affecting ecosystems, biodiversity and the climate.

Every country and region has unique opportunities and challenges in the production, use, conservation, and regeneration of their biological resources. The bioeconomy objectives of countries and regions are shaped by their political, economic, industrial, and technological contexts, biophysical and societal characteristics. For this reason, there is not one unified concept of bioeconomy. Bioeconomy is captured in a diverse range of strategies, with varying interpretations and visions of the bioeconomy. There is a diversity of bioeconomy approaches, which reflects regional, national, and sub-national circumstances and capabilities. There are also common elements that can provide opportunities for collaboration among stakeholders at all levels. The centrality of agrifood systems is one of them.

According to the FAO Dashboard on bioeconomy, some 23 countries and 3 regions have dedicated bioeconomy strategies, and approximately 15 are in the process of developing one. About 35 countries have strategies related to bioscience and biotechnology that are relevant to the agrifood sector, and an increasing number of countries are integrating bioeconomy into their national plans for biodiversity, climate action, and food systems transformation. Despite the lack of a universally agreed-upon definition of bioeconomy, agrifood systems are central to all bioeconomy strategies.

1 **UNEP (United Nations Envionmental Programme).** 2024. *Global Resources Outlook (2024): Bend the trend – Pathways to a livable planet as resource use spikes.* Nairobi, International Resource Panel. www.unep.org/resources/Global-Resource-Outlook-2024

In response to the recommendations of the 43rd Session of the FAO Conference, FAO carried out this study that informs the current discussions on bioeconomy. It provides a synopsis of FAO's contributions to achieving a sustainable bioeconomy in the food and agriculture sectors and gives insights into the multitude of approaches adopted at national and regional level, to design and implement bioeconomy pathways. The insights gathered will guide FAO and its Members in shaping the work on bioeconomy for sustainable food and agriculture and strengthening the role of agrifood systems in driving the transformative potential of the bioeconomy across other sectors.

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Abbreviations

ACTO	Amazon Cooperation Treaty Organization
BIC	Bio-based Industries Consortium
BMWG	Bioeconomy Multi-sectoral Working Group Namibia
BPI	Blue Fishing Ports Initiative
CBA	Circular Bioeconomy Alliance
CBD	Convention on Biological Diversity
EAC	East African Community
EC	European Commission
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GBEP	Global Bioenergy Partnership
GBF	Global Biodiversity Framework
GBS	Global Bioeconomy Summit
GCF	Green Climate Fund
GCI	Green Cities Initiative
GEF	Global Environmental Facility
GFFA	Global Forum for Food and Agriculture
GIB	G20 Initiative on Bioeconomy
IACGB	International Advisory Council on Global Bioeconomy
IAEA	International Atomic Energy Agency
IBF	International Bioeconomy Forum
IPCC	Intergovernmental Panel on Climate Change
ISBWG	International Sustainable Bioeconomy Working Group

JRC	Joint Research Centre [of the European Commission]
LEAP	Livestock Environmental Assessment and Performance
LCA	life-cycle assessment
LTLEDS	long-term low emissions development strategies
NAPs	national adaptation plans
NBSAPs	national biodiversity strategies and action plans
NDCs	nationally determined contributions
NTFPs	non-timber forest products
NWFPs	non-wood forest products
PPA	Programme Priority Area (FAO)
PPA BE2	Programme Priority Area "Bioeconomy for sustainable food and agriculture"
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
WBEF	World Bioeconomy Forum
WEF	water–energy–food nexus
UNFCCC	United Nations Framework Convention for Climate Change

Executive summary

During the 43rd Session of the Conference of the Food and Agriculture Organization of the United Nations (FAO), FAO Members stressed "the importance of bioeconomy for sustainable agrifood systems (...) and recognized the importance of inclusive consideration of the diverse and regionally balanced perspectives in FAO's normative, policy, and scientific work (...)".[2] In response to these recommendations and drawing on the earlier 2021 FAO study titled *How to Mainstream Sustainability and Circularity into the Bioeconomy – A Compendium of Bioeconomy Good Practices and Policies*, this study has three primary objectives: (i) to review national and regional bioeconomy strategies, with a focus on definitions, sustainability objectives, priority areas, activities, and governance mechanisms; (ii) to present FAO's contributions to a sustainable bioeconomy within the food and agriculture sectors; and (iii) to identify gaps and opportunities to guide FAO and its Members in shaping the transition to a sustainable global bioeconomy for food and agriculture.

In recent years, the concept of the bioeconomy has gained significant global traction. The concept has evolved from its early focus on resource substitution and biotechnological innovation to a more comprehensive and cross-cutting approach for sustainable development. This underscores that bioeconomy is increasingly recognized for its transformative potential to reshape the existing economic paradigm into one that is economically, environmentally, and socially sustainable.

However, the bioeconomy is not inherently sustainable. Realizing its potential requires robust measures that can ensure its development aligns with broader societal goals. Increased demand for biomass, which is central to bioeconomy development, poses challenges. For example, competition for resources may increase and international trade may be affected. Without assessing the economic, environmental and social sustainability of the bioeconomy, its development could risk exacerbating global inequalities related to resource access, environmental degradation, knowledge distribution, and land rights.

This multifaced development of the concept of bioeconomy has led to the emergence of many bioeconomy strategies with different interpretations and visions. Around 23 countries and 3 regions having a dedicated bioeconomy strategy or policy document,[3] and around

2 **FAO.** 2023a. *Report of the conference of FAO.* Forty-third Session Rome, 1-7 July 2023. FAO. https://openknowledge.fao.org/server/api/core/bitstreams/f1f7c772-8139-4931-ac88-12dc5f927220/content

3 Austria, Brazil, Canada, China, Colombia, Costa Rica, Estonia, Finland, France, Germany, Ireland, Italy, Japan, Latvia, Malaysia, Namibia, the Kingdom of the Netherlands, Norway, Portugal, South Africa, Spain, Thailand, and the United States of America. Regional bioeconomy strategies include those of the European Union, the East African Community and the Nordic Council of Ministers (FAO, 2024a).

15 currently developing one.[4] Additionally, many countries are integrating the bioeconomy into their national plans for the protection of biodiversity, climate change adaptation and mitigation, and agrifood systems transformation, which is an indication of the strong connection the bioeconomy has with sustainable development.

The diverse nature of bioeconomy strategies reflects different national and regional interpretations and visions. Previous FAO work identified fifteen common objectives when developing a strategy. In preparation of this study, FAO conducted a global review of national and regional bioeconomy strategies, highlighting both shared elements and unique characteristics, finding that the fifteen objectives common to all bioeconomy strategies are all intrinsically linked to agrifood systems.

Environmental objectives focus on replacing fossil-based resources with sustainable biological resources, addressing production challenges, and integrating climate and biodiversity goals. The bioeconomy strategies that were analysed emphasize resource efficiency, waste minimization, and the cascading use of biomass, and are aligned with international agreements. Economic objectives are centred on adding value to biomass to foster inclusive rural and urban development to ensure the equitable distribution of benefits, empowering local communities, increasing access to markets, and the development of new value chains. Social objectives prioritize safeguarding food security, supporting vulnerable communities, and raising consumer awareness by looking at the demand side in addition to the supply side.

Effective governance and robust monitoring systems, that should involve dedicated institutions and mechanisms to maximize synergies, minimize trade-offs, and tackle challenges, are essential. Integrating traditional knowledge with modern science, technology, and innovation accelerates the development of a sustainable bioeconomy.

Over the past decade, FAO has contributed to global bioeconomy development by supporting countries in formulating and implementing bioeconomy strategies. FAO has become the first UN agency to make the bioeconomy a corporate priority, focusing on policy advisory, capacity building, partnerships, and knowledge creation.

4 Argentina, Croatia, Czechia, Ecuador, Hungary, India, Lithuania, Mexico, Paraguay, Poland, Slovakia, Sweden, Switzerland, Türkiye, Uruguay (FAO, 2024a).

The study concludes with the following gaps and opportunities to guide FAO and its Members in shaping the work on bioeconomy for food and agriculture:

1. Bioeconomy policies, strategies, and plans need to 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.

2. A multilaterally agreed bioeconomy framework and sustainability criteria and indicators are critical to the successful implementation of the bioeconomy approach, ensuring they reflect national circumstances and capabilities, are supported by empirical data and aligned with the Sustainable Development Goals (SDGs).

3. By establishing intersectoral governance mechanisms for bioeconomy, countries and regions should aim for increased policy coherence with relevant sustainable development frameworks. Leveraging the FAO Bioeconomy Toolbox and the FAO Dashboard on bioeconomy, among other resources, could assist countries in designing sustainable bioeconomy strategies and facilitate the exchange of good practices.

4. The principles of a just transition should be recognized and integrated into bioeconomy policies, strategies, and plans to ensure that no one is left behind, including small-scale agricultural producers, Indigenous Peoples, women, youth, and other vulnerable groups. Greater investments in education, training, and empowerment of youth, women, and vulnerable groups should aim at providing them with equal opportunities to participate in the bioeconomy.

5. Increased resources are required to foster inclusive and equitable bioeconomy development in rural and urban areas promoting local bio-based value chains that valorize waste, residues, and by-products, while encouraging decentralized biomass processing. Boost rural and urban entrepreneurship, innovation, and job creation through policy incentives, technical assistance, training, and investment. These efforts could be further integrated into FAO's flagship initiatives, including the Green Cities Initiative, One Country One Priority Product, and the Hand-in-Hand Initiative.

6. 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.

7. Increased investments in bioeconomy science, technology, and innovation are crucial for supporting the transformation of agrifood systems, including crop and livestock production, fisheries and aquaculture, and forestry in low- and middle-income countries, utilizing funds like the Adaptation Fund, the Global Environmental Facility (GEF), and the Green Climate Fund (GCF). Some key priority areas include

enhancing south-south and triangular cooperation for technology transfer, promoting circular business models with demand-side measures, expanding from agricultural biotechnologies to new bio-based products, regenerating degraded areas through bioremediation and microbiome innovations, and applying behavioural science to encourage sustainable consumption of bioeconomy products.

8. The coordinated and synergistic actions needed to advance sustainable bioeconomy development would be bolstered by the establishment of a global multi-stakeholder platform or partnership with the participation of United Nations organizations. FAO could become a global convener of such a mechanism. It would help strengthen the role of food security and nutrition and agrifood systems transformation as key pillars of sustainable bioeconomy development. The global platform or partnership should serve as a catalyst for developing policies, strategies, and plans; building capacities; exchanging knowledge; and creating incentives for bioeconomy development at all levels.

9. Globally harmonized efforts are essential to support bioeconomy data collection and analysis, focusing on biomass availability, potential applications, and scenario modelling for policy development, among others. Open access to bioeconomy data should be promoted where feasible. Integrating bioeconomy indicators into existing sustainable development and environmental reporting frameworks will streamline efforts and enhance policy coherence. Establishing common criteria and practical indicators for sustainable bioeconomy, aligned with the FAO Aspirational Principles and Criteria for a Sustainable Bioeconomy and other relevant standards, could increase transparency and accountability, thereby informing investments and fund allocation in the bioeconomy sector.

10. To address the demand side of bioeconomy development, targeted support is required in several key areas. This includes enhancing consumer education on the benefits and value of bio-based products and promoting transparent labelling and certification to build consumer trust. Advocacy for policy changes to reduce subsidies for unsustainable alternatives is crucial, as is supporting research on consumer behaviour to inform marketing and product development. Efforts should focus on fostering innovation to lower costs associated with bio-based products and encouraging sustainable consumption patterns through guidelines and tools. Additionally, facilitating stakeholder collaboration to share good practices and align efforts is essential.

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Chapter 1. Introduction

In recent years, the concept of the bioeconomy has captured global attention. An increasing number of countries are actively engaged in developing their own. At the same time, the concept of bioeconomy has evolved significantly. From an initial emphasis on resource substitution and biotechnological breakthroughs, bioeconomy now encompasses a broader framework for sustainable development based on production, utilization, conservation, and regeneration of biological resources.

In the 1970s, the concept of bioeconomy was described by Nicholas Georgescu-Roegen as a transformational pathway towards a degrowth society (Backhouse *et al.*, 2021). Later on, geneticists Juan Enriquez Cabot and Rodrigo Martinez highlighted the transformative potential of genomics and biotechnology in industrial processes in defining bioeconomy (Von Braun, 2014). In the early 2000s, bioeconomy gained prominence as a policy concept in Europe. The European Commission (EC) introduced the idea of a knowledge-based bioeconomy with a dual perspective: (i) the resource substitution perspective that focuses on "renewable industrial feedstock to produce biofuels, biopolymers and chemicals"; and (ii) the biotechnology innovation perspective that views biotechnology as "an important pillar of Europe's economy by 2030, indispensable to sustainable economic growth, employment, energy supply and to maintaining the standard of living" (European Union, 2007).

After 2012, the concept of the bioeconomy expanded globally. The first European Union bioeconomy strategy was published, the United States of America released its National Bioeconomy Blueprint, Malaysia established its Bioeconomy Transformation Program, and a year later South Africa formulated its bioeconomy strategy. In the United States' National Bioeconomy Blueprint, the bioeconomy is "based on the use of research and innovation in the biological sciences to create economic activity and public benefit" (United States of America, 2012); in the South African strategy, bioeconomy encompasses "biotechnological activities and processes that translate into economic outputs, particularly those with industrial application" (South Africa, 2013).

However, biotechnological innovations do not inherently guarantee sustainability. The food price crisis of 2008-2009 and related discussions shed light on potential impacts of biofuel policies on food prices (CFS, 2013). The debates highlighted the delicate balance between food security and the use of biomass for energy, which emphasizes the critical need for sustainability within the bioeconomy. While early bioeconomy definitions did not address explicitly sustainability objectives, the evolved discourse on bioeconomy increasingly recognized the need to integrate sustainability considerations into the bioeconomy framework (Birner, 2018).

The evolving global consensus among experts resulted in the revised definition of bioeconomy in the Communiqué of the 2015 Global Bioeconomy Summit:

> Bioeconomy is defined in different ways around the world. We have not aimed for a unified definition but note that an understanding of 'bioeconomy as the knowledge-based production and utilization of biological resources, innovative biological processes and principles to sustainably provide goods and services across all economic sectors' is shared by many (GBS, 2015).

The 2018 Global Bioeconomy Summit introduced conservation of biological resources as an additional dimension of bioeconomy, the next 2020 Global Bioeconomy Summit added regeneration of biological resources.

The concept of circularity gradually became an important aspect of the bioeconomy as well. Circular bioeconomy approaches reduce trade-offs and increases synergies (Lang, 2022). The Communiqué of the 2015 Global Bioeconomy Summit emphasizes the need to align the principles of a sustainable bioeconomy with circularity principles, which "would involve systemic approaches across sectors (i.e. nexus thinking), particularly innovation policy measures that aim at optimizing Bioeconomy value networks and minimizing waste and losses" (GBS, 2015). The integration of circularity into the bioeconomy has led to the development of the concept of a "biomass-based value web". This concept takes into account the cascading use of biomass[5] and the use of by-products from biomass processing, linking different value chains (Virchow *et al.*, 2016).

The increasing focus on sustainability has anchored bioeconomy in the broader context of sustainable development. This perspective underscores the transformative potential of the bioeconomy to reshape the existing economic paradigm into one that is economically, environmentally, and socially sustainable.

Good governance principles became essential to guide the alignment of the bioeconomy with broader societal goals. It bears repeating that bioeconomy is not inherently sustainable. One valid critique that has been expressed is that the implementation of many bioeconomy strategies will require a substantial increase of biomass production (Backhouse *et al.*, 2021). To address the needs of a global population, which is projected to increase to 9.7 billion people by 2050, it is imperative to significantly increase by some estimated 50 percent above 2012 levels – biomass production for food, feed, and biofuel. The impacts of climate change and growing climate risks would make it more challenging and urgent to address (FAO, 2017). The increased demand for biomass will unavoidably go hand in hand with increased competition for the use of biomass and will affect international trade flows (ibid.). Without managing sustainability risks of bioeconomy development across environmental, economic, and social dimensions, global inequalities related to access to natural resources, exposure to environmental degradation, knowledge production, and land rights could be exacerbated (ibid.).

5 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).

In contrast to the well-established fossil-based economy, the bioeconomy is a relatively recent development. As a result, it lacks the extensive technological infrastructure, expertise, and investments that the fossil-based economy has accumulated over time. Although the bioeconomy is experiencing rapid growth, many stakeholders are expressing concerns about its capacity to deliver mutually beneficial outcomes for all stakeholders involved. They are calling for regulations on bioeconomy development out of concern for how biomass is sourced, how land is used, and the conflicts of interest that can arise from these activities (Meyer, 2017). To ensure sustainability across all dimensions, it is crucial to strike a balance between implementing and evaluating the bioeconomy and fostering an environment that encourages learning and progress to better account for adverse outcomes and mitigate their impact. Guidance on the development of the bioeconomy should prioritize sustainability, equity, and inclusiveness while fostering innovation to achieve win–win situations. At the same time, consideration must be given to the possibility that regulations on bioeconomy development may have disproportionate impacts on small-scale agricultural producers compared to large corporations or stakeholders with substantial resources.

While there is not one universally agreed-upon definition of what constitutes a bioeconomy and its development is always context specific, agrifood systems[6] are commonly at the centre of bioeconomy strategies. In their bioeconomy strategies, countries and regions generally share common objectives of enhancing food security and nutrition, reducing greenhouse gas emissions, minimizing waste and promoting circularity, increasing competitiveness, and fostering inclusion through innovation. Through bioeconomy strategies, countries not only aim to make agrifood systems more sustainable, but also to leverage the potential of agrifood systems for

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6 Agrifood systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products. They comprise all food products that originate from crop and livestock production, forestry, fisheries and aquaculture, as well as the broader economic, societal and natural environments in which these diverse production systems are embedded (FAO, 2021c).

advancing the whole economy, creating and connecting new industries, generating decent employment opportunities, and increasing social well-being (Meyer, 2017; FAO, 2024a). Encompassing a wide range of sectors, such as construction and health, the bioeconomy extends beyond agrifood systems, connecting them with the broader economy as biomass and biological resources flow through all economic sectors.

A common vision among most of the strategies is that the bioeconomy should generate additional value within agrifood systems by using and valorising existing resources more effectively and tapping into previously neglected resources such as waste, residues, and by-products (Meybeck *et al.*, 2024a). For instance, in Asia and the Pacific, countries focus more on the development and application of biosciences, specifically biotechnology, to improve the sustainability, productivity and resilience of agrifood systems. In Latin America and the Caribbean, the use of abundant biodiversity (e.g. non-wood forest products) is central to delivering environmental, social, and economic benefits, especially in rural areas and with the inclusion of Indigenous Peoples and local communities.

To embrace these different visions and perspectives, FAO adopted the definition of the 2020 Global Bioeconomy Summit Communiqué as its working definition in the context of the Strategic Framework 2022–2031 Programme Priority Area (PPA) on bioeconomy for sustainable food and agriculture: "The bioeconomy 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, 2021a). Some countries, such as Colombia and Costa Rica, have adopted the same definition, and there is a close similarity with the definition adopted by Germany.[7]

During the 43rd Session of the FAO Conference, FAO Members stressed "the importance of bioeconomy for sustainable agrifood systems (...) and recognized the importance of inclusive consideration of the diverse and regionally balanced perspectives in FAO's normative, policy, and scientific work (...)" (FAO, 2023a). In response to these recommendations and drawing on the earlier 2021 FAO study titled *How to Mainstream Sustainability and Circularity into the Bioeconomy – A Compendium of Bioeconomy Good Practices and Policies* (Gomez San Juan and Bogdanski, 2021), this study has three primary objectives: (i) to review national and regional bioeconomy strategies, with a focus on definitions, sustainability objectives, priority areas, activities, and governance mechanisms; (ii) to present FAO's contributions to a sustainable bioeconomy within the food and agriculture sectors; and (iii) to identify gaps and opportunities to guide FAO and its Members in shaping the transition to a sustainable global bioeconomy for food and agriculture.

This study complements the recently published FAO position paper titled "Bioeconomy for sustainable food and agriculture: a global opportunity" (FAO, 2024b). While the position paper is tailored to inform bioeconomy discussions, including those in the G20 Initiative on Bioeconomy (GIB) and the related High-Level Principles on Bioeconomy, this study aims to guide FAO and its Members in shaping the work on bioeconomy for sustainable food and agriculture,

7 In the 2020 revised Germany bioeconomy strategy, bioeconomy is defined as "the production, exploitation, and use of biological resources, processes, and systems to provide products, processes, and services in all economic sectors within the frame of a sustainable economic system." (BMBF and BMEL, 2020)

strenghtening the role of agrifood systems in driving the transformative potential of bioeconomy across other sectors.

This study focuses exclusively on dedicated bioeconomy strategies at the national and regional level (listed in Appendix 2) that reflect the different perspectives of these countries and regions on the development of their different bioeconomies. Although most of the current bioeconomy strategies are implemented in high-income countries, a growing number of low- and middle-income countries are in the process of developing bioeconomy strategies as well. It does not cover the means of implementation (e.g., policy development, investments, and trade), which are highly context-dependent, or subnational strategies.[8] This study provides a general framework and examples but does not outline guidelines for how to implement bioeconomy in different contexts.

It is also important to note that, unlike for other national planning instruments, there is no global definition for what constitutes a bioeconomy strategy. Many strategies are explicitly defined as a "bioeconomy strategy", "bio-strategy" or "bio-based economy strategy", but they often differ in approach and terminology. For instance, the strategy of the United States has been established through an "executive order", whereas in Malaysia the strategy is a "biotechnology strategy" implemented by the "Malaysian Bioeconomy Corporation". Despite these distinctions, these documents reflect the respective country's commitment to develop a holistic bioeconomy, domestically and internationally. For the purposes of this study, a "bioeconomy strategy" is defined as "a programmatic document that outlines the building blocks and strategic directions for deploying a bioeconomy in a country." The International Advisory Council on Global Bioeconomy identifies four defining elements of a bioeconomy strategy: i) long-term consequences; ii) a significant relationship to a central purpose; iii) a defined acting subject; and iv) concerns for actual choices and prioritization (IACGB, 2020). A "bioeconomy-related strategy" refers to a sectoral and targeted plan or initiative that addresses specific aspects or sectors (e.g. biofuels, biotechnology, or agriculture) within the broader bioeconomy. Unlike comprehensive bioeconomy strategies, which encompass a wide range of biological resources and economic sectors, bioeconomy-related strategies focus on specific areas or applications within the bioeconomy.

BOX 1. Bioeconomy lexicon

To understand and navigate the dynamic and evolving landscape of the bioeconomy, it is necessary to be familiar with bioeconomy terminology. Many new words and terms related to biological systems have emerged. Appendix 1 provides a bioeconomy lexicon. The lexicon is purely informative and collects definitions of bio-prefixed words based on the glossary collected by FAO bioeconomy publications, the FAO Terminology Portal, the International Resource Panel of the United Nations Environment Programme (UNEP), the European Commission Knowledge Center for Bioeconomy Glossary, the FAO Glossary of Biotechnology and Genetic Engineering, and the National Institute of Standards and Technology (NIST).

8 Subnational strategies are included in subchapter 2.6 "Intersectoral policies and the enabling environment for a sustainable bioeconomy", but they have not been considered for the purpose of the analysis itself.

Chapter 2. Bioeconomy perspectives: towards common objectives

FAO has identified 15 major sustainability objectives that drive the development of the bioeconomy (Gomez San Juan and Bogdanski, 2021) (see Appendix 3 for further details). These objectives encompass the social, economic, and environmental dimensions of sustainability, and the strategies and initiatives are underpinned by specific governance arrangements. Table 1, which shows the different shared sustainability objectives and links them with the related SDGs targets, highlights the prominent role bioeconomy plays in achieving Sustainable Development Goals (SDGs).

Not all the strategies incorporate every objective or have the same combinations of objectives. Environmental objectives promote the efficient use of renewable resources to replace fossil-based resources, and a strong focus is placed on circularity and cascading use of biological resources, the conservation of biodiversity, and climate change mitigation. Economic objectives aim to add value to biomass, stimulate rural development, and create jobs, within the framework of inclusive economic growth. Social objectives focus on ensuring food security, enhancing nutrition, and supporting vulnerable communities. Integrating provisions to promote gender equality and encourage the participation of young people is essential for an inclusive bioeconomy that delivers equal benefits for all. Most bioeconomy strategies also include the creation of governance structures, enabling environments and monitoring systems to track progress (Gardossi *et al.*, 2023).

The 2021 review (Gomez San Juan and Bogdanski, 2021) highlighted significant gaps in global bioeconomy development. One of the major obstacles hindering the development of a sustainable bioeconomy is the lack of bioeconomy-related data. Data are essential to inform policymakers in the development of effective and sustainable bioeconomy strategies, and to monitor their sustainability over time. Also, as bioeconomy is a cross-cutting approach that involves diverse sectors and stakeholders, its governance requires that policies are coherent, and the strategies consider holistically the different trade-offs that the development of a bioeconomy intrinsically brings.

TABLE 1. Common sustainability objectives 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

Continues on the next page

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: **Gomez San Juan, M. and Bogdanski, A.** 2021. *How to mainstream sustainability and circularity into the bioeconomy? A compendium of bioeconomy good practices and policies.* Rome, FAO. https://www.fao.org/3/cb5798en/cb5798en.pdf

2.1. SUSTAINABLE PRODUCTION AND UTILIZATION OF BIOLOGICAL RESOURCES TO SUBSTITUTE FOSSIL-BASED RESOURCES AND IMPROVE ENVIRONMENTAL OUTCOMES

Most bioeconomy-dedicated strategies share the common objective of harnessing biological resources to serve as substitutes for fossil-based and other non-renewable resources, or reduce reliance on them, in all economic sectors. The bioeconomy is seen as a pathway for advancing "defossilization" – a transition from fossil to renewable carbon feedstocks in secondary production sectors (Carus *et al.*, 2020; IEA, 2022; Zuiderveen *et al.*, 2022). Carbon is a common element of all bio-based materials, and renewable carbon is obtained in large part from agricultural production, organic waste and microorganisms, placing agrifood systems at the heart of the bioeconomy.

The FAO Dashboard on bioeconomy provides information on the economic sectors and specific bio-based secondary production industries that countries are prioritizing in their dedicated bioeconomy strategies. Figure 1 summarizes the contribution of different economic sectors to national and regional bioeconomies derived from the proposed sector-specific actions in the dedicated bioeconomy strategies worldwide.

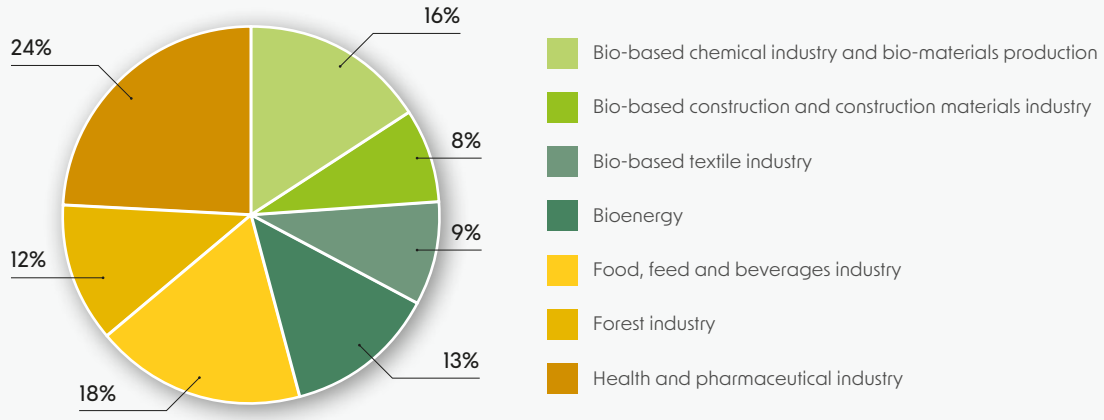
Among specific actions countries and regions prioritized are designing legal frameworks for fostering bio-based chemicals and materials, including cellulose-based materials and packaging; the exploration of traditional medicine and natural compounds, along with advanced biotechnologies, to produce bio-pharmaceuticals and improve disease prevention and diagnostics; investments in biorefineries, and in the use of functional microorganisms, enzyme formulations, and biotechnologies in production processes.

Beyond biomass, countries are also exploring the use of microorganisms and biological sciences for natural resources management. For instance, Malaysia is exploring new microbes and enzymes for bioremediation and sustainable biochemistry.

Along with bio-based products, bio-based services are an important part of bioeconomy strategies. These services include knowledge-based services (e.g. scientific activities, engineering), services related to management of natural resources (e.g. recreation activities, ecotourism), and services related to treating waste materials (wastewater and waste treatment, soil remediation, and recycling) (Gomez San Juan and Bogdanski, 2021).

Biological processes, such as those involving microorganisms (e.g. bacteria and enzymes), offer environmentally friendly alternatives for the treatment of waste streams, producing materials with less pollution, and reducing the use of energy, water and land. These microbial processes, which often have high growth and efficiency rates, take advantage of the natural abilities of living organisms that have evolved over millions of years to specialize in catalysing desired processes and producing useful by-products. Microbial processes can also serve as a substitute for chemical and thermo-chemical processes. The application of biotechnology in various sectors can be used in the production of food, bio-based plastics, enzymatic detergents, biofuels, construction materials, textiles and biofertilizers (Zafar *et al.*, 2022).

FIGURE 1. Bio-based secondary production industries prioritized by national and regional bioeconomy strategies worldwide



Source: **FAO.** 2024. *Dashboard on bioeconomy strategies and related actions for sustainable development.* [online]. Rome. [Cited 4 June 2024]. www.fao.org/in-action/sustainable-and-circular-bioeconomy/dashboard/en/

Actions supporting an enabling environment for bioeconomy often include development of databases integrating biological and cultural data for natural resources management; employing innovative technologies and social strategies for sustainable management, conservation and rehabilitation of bioresources; incentivizing the use of bio-based agricultural inputs to minimize impacts on biodiversity (Box 2); and preserving forested watersheds to support water conservation.

However, the design and implementation of a sustainable bioeconomy requires an assessment of the amount of biomass that agrifood systems can provide to replace fossil carbon and still meet the demand of current and future production systems, without leading to unacceptable trade-offs for other sustainability objectives, including food security and biodiversity conservation (Giuntoli *et al.*, 2023). Many strategies recognize the need to address sustainability challenges and trade-offs related to the production and utilization of biological resources, and consider the protection and enhancement of biodiversity, soils, water, and ecosystems.

To address resource scarcity and trade-offs in the use of biomass, circularity and cascading use of biological resources play an important role in bioeconomy strategies. Almost all countries have integrated circularity into their strategies to enhance the value of fully closed resource loops; maximize the secondary usage of biomass from crops, livestock, forests, and fisheries and aquaculture; and generate new sustainable raw materials. In these countries, circular bioeconomy approaches aim to minimize waste streams and reintegrate them into the production cycle as inputs rather than discarding them.

BOX 2. CASE STUDY **Bio-inputs for plant health in Costa Rica**

Bio-inputs include bio-based products such as biofertilizers, biopesticides, bio-stimulants and beneficial invertebrates that contribute to plant health and productivity. For example, bio-inputs can be produced from fungi and bacteria, as well as bio ferments. Services can also be produced, such as microbiological soil surveillance. Microbial inputs can also be used in animal husbandry. For instance, probiotics added to feed or prebiotics included in feed rations.

The Bioeconomy Strategy of Costa Rica includes the promotion of bio-inputs as a priority action, to improve access to them by smallholder farmers such as the transfer of technology for the production of bio-inputs in small bioindustries for farms or cooperatives. This involves establishing a legal framework and supporting projects that increase the value added through bio-inputs. This is expected to consolidate the bioeconomy as a model for sustainable growth in the country.

The Ministry of Agriculture and Livestock of Costa Rica has developed a guide for the preparation and application of bio-inputs, and in 2023, Costa Rica launched the first National Forum for Bio-inputs. The country adheres to a series of regulations common to all Central America for some types of bio-inputs. However, the regulatory framework for registering bio-based pesticides still needs to be updated to align with the bioeconomy strategy (Dietz *et al.*, 2024).

Source: **Dietz, T., Bogdanski, A., Boldt, C., Börner, J., von Braun, J., Choncubhair, N., Durham, B., Ecuru, J., Lang, C., Li, Y., Lund, M., Macrae, E., Maxon, M., Miranda, H., Mizunashi, W., Mungeyi, P., Hara, I., Lucía, P., Fonseca, V. and Wehrheim, P.** 2024. *Bioeconomy globalization: Recent trends and drivers of national programs and policies A report by the International Advisory Council on Global Bioeconomy (IACGB).* www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/52440fb0-f35d-11ee-9ed1-dead53a91d31/current/document/Global_Bioeconomy_-_April_2024_IACGB.pdf

Circularity features in most strategies, but it is especially prominent and one of the major objectives in bioeconomy strategies of Austria, Estonia, Finland, Italy and Portugal. Costa Rica promotes circularity in the management of urban waste streams as means supporting green cities. Austria has prioritized circularity as a standalone objective, integrating it across all priority areas and sectors. The strategy focuses on enhancing cascading use of biomass, standardizing secondary raw materials, exploring the boundaries of the circular economy, and increasing public awareness of bioeconomy. Finland introduced several measures to bridge bioeconomy and circular economy. Malaysia is harnessing agricultural and industrial waste to create added value and establishing a robust chain ecosystem to foster a circular economy in the production and consumption of bio-based products. To foster economic growth and provide opportunities for small-scale farmers and small and medium enterprises, the East African Community is promoting the creation of added value to agricultural waste and by-products by using these resources to produce bio-based products such as bio-based textiles, biomass briquettes, and biogas.

Cascading use enhances resource efficiency by reusing residues and recycling materials throughout the value chain and reduces the need to introduce new materials into the economy (Ellen MacArthur Foundation, 2013). This approach, which involves processing biomass into bioproducts that undergo single or multiple uses before disposal, extends the availability of biomass within a system. The cascading use of biomass, which is connected to the concept of circularity, creates biomass-based value webs that encompass the interconnected relationships within and between value chains (Gomez San Juan, Bogdanski and Dubois, 2019). Several countries envision the cascading use of biomass across different sectors. Italy aims to develop new processes for converting residues and side streams into bio-products and bioenergy. Latvia promotes the cascading use of biomass to ensure sustainable land management and efficient resource utilization. Germany focuses on maintaining biological materials within a circular cycle for as long as possible. Estonia plans to develop biorefineries operating on the cascading use principle, producing bio-based materials and chemicals along with energy. Portugal intends to accelerate sustainable aquaculture using industrial symbiosis and the cascading use of resources.

Substituting fossil-based and non-renewable resources, making efficient use of biomass, and keeping its value as much as possible in the system can deliver a range of environmental benefits. For example, reducing carbon emissions through the replacement of fossil-based materials and inefficient processes, and sequestering carbon in bio-based products contributes to climate change mitigation and adaptation (Gomez San Juan, Harnett and Albinelli, 2022a). Sustainable farming, fishing, and forestry practices, which reduce pollution and increase resource efficiency, can protect biodiversity (Gomez San Juan, Harnett and Albinelli, 2022b). Efforts in this area, in turn, can alleviate resource scarcity and reduce changes in land use, which is a main cause of sustainability tradeoffs (Gardossi *et al.*, 2023). Advancements in technologies can support the reduction of food loss and waste by creating new foods, food ingredients and bioactive compounds, and other bio-based products (e.g. textiles or compost).

Several countries have identified bioeconomy as a part of a larger strategy to achieve their climate and biodiversity objectives. Some countries have included bioeconomy practices in their climate and biodiversity agenda, and others explicitly include bioeconomy strategies and policies as key elements in their pathway towards reaching the targets laid out in the Paris Agreement and in the Kunming-Montreal Global Biodiversity Framework (FAO, 2024a).

In Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs), Colombia has underscored the importance of bioeconomy for safeguarding ecosystems (Colombia, 2020), Costa Rica has focused on decarbonization and climate resilience (Costa Rica, 2020), and Haiti has committed to developing a national bioeconomy in tandem with climate-smart agriculture and integrating it into its NAP to increase climate resilience (Haiti, 2022). New Zealand plans to collaborate with Indigenous Peoples to develop a bioeconomy strategy (New Zealand, 2021a). South Sudan focuses on nurturing an environmentally friendly bioeconomy and preserving biodiversity and promoting efficient utilization of biomass in all sectors (South Sudan, 2021). Uruguay's NAP, which acknowledges FAO support in drafting Uruguay's bioeconomy strategy, harnesses bioeconomy to shift to a low-carbon economy, optimizing biological resource utilization, promoting production diversification, and contributing to climate change adaptation and mitigation efforts (Uruguay, 2019).

It is noteworthy that 22 countries have identified bioeconomy as a means to reach long-term emission reduction objectives in their Long-term Low Emissions Development Strategies (LTLEDS). For instance, New Zealand prioritizes the bioeconomy for economic regeneration to create a thriving economy through the innovative use of renewable resources (New Zealand, 2021b). Portugal emphasizes forest-based bioeconomy expansion for carbon sequestration (Portugal, 2019), and Spain is focusing on research and innovation in the agriculture and forestry sectors to reduce greenhouse gas emissions (Spain, 2020).

In National Biodiversity Strategies and Action Plans (NBSAPs) and Biodiversity Reports, the bioeconomy is often linked with sustainable resource management, the promotion of biodiversity-based industries, and the integration of traditional knowledge, innovation, and capacity building. These strategies prioritize the sustainable use of biological resources and industries reliant on biodiversity (e.g. ecotourism and biotechnology) and ensure bioeconomy activities align with biodiversity conservation goals. Some countries also emphasize the incorporation of traditional knowledge into bioeconomy strategies in conjunction with their efforts to advance innovation and technology for sustainable production methods and value-added products. For example, Brazil aims to restore and preserve vital ecosystems (Brazil, 2023a). Canada focuses on environmental sustainability, clean technology, and rural economic development (Canada, 2014). Finland integrates biodiversity values into its forest management programme (Finland, 2014; Finland, 2016). Haiti seeks to harness biodiversity for innovation and wealth creation (Haiti, 2016). Indonesia fosters collaboration for the development of a national bioeconomy (Indonesia, 2003).

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2.2. ADDING VALUE TO BIOMASS, SUPPORTING RURAL AND URBAN DEVELOPMENT, PROMOTING MARKET ACCESS, AND FACILITATING TRADE

Various economic objectives are prominent in bioeconomy strategies of Finland and Norway. Both countries are working to create economic growth and decent jobs based on sustainable solutions that can create the highest possible value-added products and services. Thailand is looking at generating additional value not just from bioresources, but also using traditional knowledge. Colombia promotes the generation of bioproducts of high added value by strengthening regulatory frameworks that facilitate their development, with the goal of securing human well-being. Costa Rica sees bioeconomy as one of the pillars of productive transformation that generates additional value. Latvia has established clear, measurable targets to quantify bioeconomy's benefits to the whole economy. In Italy, the creation of economic value from local biodiversity and promotion of circularity are the priorities in the development of the bioeconomy. This is similar to the approach taken in Japan, where value addition is also strongly connected to circularity. The East African Community's regional approach aims at creating structures for innovation and deployment of technologies and know-how for value addition to primary production and biowaste.

Value-adding production measures listed in dedicated bioeconomy strategies generally fall into the three major categories: product diversification, efficient resource utilization and circular approaches, and production of high value-added products. By utilizing biological resources in innovative ways, bioeconomy creates a wide range of non-traditional products. This diversification expands market opportunities and adds value to biomass. For instance, forest industries are branching into diverse sectors, producing food, chemicals, medical products, energy, nanoproducts (Perumal *et al.*, 2022), textiles, and construction materials that provide eco-friendly, innovative alternatives to traditional materials. Bioeconomy processes often extract maximum value from biomass by utilizing by-products, co-products, and waste, thereby reducing waste and maximizing value creation throughout the product lifecycle. For example, Finland promotes the processing of abundant but underutilized fish species, algae, and side streams from the fisheries industry to produce high-value products such as nutritional supplements, cosmetics, and pharmaceutical-like products, while Papua New Guinea implements new post-harvest processing technologies to improve the quality and commercial potential of non-wood forest products, such as indigenous trees with nutritious nuts (Wallace *et al.*, 2022). Many countries expand the use of recovered materials as a priority feedstock for pulp mills and promote the use of waste and residues from forest-based feedstock for bioenergy (FAO and ECOSOC, 2023).

Countries often focus on developing high value bioproducts, such as pharmaceuticals, biofuels, bioplastics, and speciality chemicals, which command high prices in the market. Examples include Malaysia focusing on high-value marine food and Namibia developing pharmaceuticals derived from indigenous biological resources. Current trends related to healthy and sustainable lifestyles, as well as new demands for healthy, "natural", sustainable, and experiential products and services, have led to a revival of non-wood forest products in many parts of the world (Martínez de Arano *et al.*, 2021; Weiss *et al.*, 2019; Weiss, Ludvig, and Živojinović, 2023).

The added value generated through bioeconomy development has the potential to create employment opportunities and foster economic growth in rural, urban, and peri-urban communities. Demand for sustainable materials, which originate in rural areas brings jobs, social security, and opportunities for development in both rural and urban environments (WBCSD, 2020). Many bioeconomy strategies aim at promoting rural development and revitalizing both rural and urban areas by creating and securing employment though local value addition. Innovative technologies in the bioeconomy can open new possibilities for production that can add value locally. Biorefineries, for example, make it possible to improve and expand many traditional value chains or develop new ones. Locating biomass processing, clusters and other mechanisms, close to production sites, can enhance rural economic resilience create decent jobs, and deliver environmental benefits by making value chains shorter (Box 3). Bioeconomy development has led to the emergence of new niches for generating income, particularly for non-wood forest products and wild edible species in the food industry. This growth has been driven by the discovery of various bioactive compounds and nutritional attributes that can be used for developing innovative products, such as nutraceuticals, functional foods, and alternative ingredient sources (Baydoun *et al.*, 2023; FAO, 2021a; Vinha *et al.*, 2016).

However, without careful consideration, there is the risk that bioeconomy development could concentrate value at certain points in the value chain. This concentration could potentially lead to an inequitable distribution of benefits that would particularly affect small-scale producers and marginalized communities (Börner, Kuhn and von Braun, 2017; Mac Clay and Sellare, 2017). To ensure fair and inclusive growth, the equitable distribution of value and benefits throughout the value chain is crucial, and this has been acknowledged in various bioeconomy strategies. For example, Italy supports the diversification of production in farms and forests to retain added value within rural economies. The East African Community aims for economic growth and opportunities for small-scale agricultural producers and small and medium enterprises by producing diverse, novel food and feed products that can improve rural livelihoods and food security. Latvia focuses on boosting agriculture and rural development for greater added value and employment. Spain encourages the sustainable use of biomass to create new business opportunities in rural areas.

Countries are working to improve market access for sustainable bioeconomy products, establish equitable and sustainable value chains and enhance the exchange of information. Efforts include connecting biomass producers with bioproduct companies to foster collaboration and supporting research that benefits both parties. In a value web approach, an ecosystem of industries and value chains work together around the same biomass feedstocks (FAO and UNECE, 2023). Some countries focus on empowering local communities by improving their access to markets and encouraging new value chains for indigenous and local products. Bioeconomy platforms are also being established to act as hubs for sharing information, disseminating good practices, and building partnerships. These platforms are essential for increasing transparency in decision making and advocating for policies that support sustainable bioeconomy development.

BOX 3. CASE STUDY Public-private partnership mechanisms to enable the deployment of biorefineries

The Circular Bio-based Europe Joint Undertaking (CBE JU) is a EUR 2 billion public-private partnership between the European Commission and the Bio-based Industries Consortium (BIC). This joint undertaking is a body of the European Union that provides funding through the Horizon Europe Programme and supports the scaling up of bio-based and circular projects in the European Union. The CBE JU and its predecessor programme, the Bio-based Industries Joint Undertaking, were created as part of the implementation of the EU bioeconomy strategy. This public-private partnership supports the regional enabling environment for sustainable businesses, the inclusion of farmers in the addition of value and in selection of how to best manage natural resources. CBE JU funds projects that provide bio-based approaches, materials and products made primarily from sustainably sourced biomass, organic waste and second-generation (non-food) feedstocks that come from agriculture, forest, fisheries and aquaculture, biowaste, biogenic gaseous carbon, among others. BIC has more than 240 members, including 38 large companies, 44 small and medium enterprises and 19 regional clusters, which represent other small and medium enterprises. BIC embraces a broad mix of sectors including agriculture, food and feed, aquatic and marine, chemicals and materials, technology providers, forestry and pulp and paper, waste management, etc. BIC, which advocates for incentives for the use of renewable feedstocks, materials and products, supports maximizing synergies between private, public, national, regional funding schemes and the prompt issuance of permits for first-of-a-kind biorefineries (Dietz *et al.*, 2024).

Blue biorefineries valorize fishery products to create market opportunities. They utilize marine-based feedstocks (e.g. algae) to produce a range of high-value products. These biorefineries are often inserted into clusters that include other bioindustries since they often use biomass in a cascading way. For example, algae can be used in health-promoting food ingredients, protein rich feed, and cosmetic formulations. Fisheries value chains can be improved by connecting them to blue biorefineries and clusters that increase access to new markets.Biorefineries are often the first step in the development of clusters or hubs. The Italian Technology Cluster for Blue Growth (BIG) links around 31 public entities, 41 private entities and 10 regional (sub-national) ones. BIG works to integrate public and private research and generate new opportunities for technological development and innovation in the national marine and maritime industries. Bioeconomy activities in the blue sector in Italy include fisheries and marine aquaculture; the exploitation of marine algae, microbes, enzymes, and by-products and biowaste produces from the processing of fishery and aquaculture products; the monitoring and bioremediation of marine water and sediment systems; and approaches for dealing with emerging pollutants. The Italian strategy also supports bioprospecting projects that can exploit in a sustainable manner deep sea biosystems and coastal areas (Italy, 2019).

Sources: **Dietz, T., Bogdanski, A., Boldt, C., Börner, J., von Braun, J., Choncubhair, N., Durham, B., Ecuru, J., Lang, C., Li, Y., Lund, M., Macrae, E., Maxon, M., Miranda, H., Mizunashi, W., Mungeyi, P., Hara, I., Lucía, P., Fonseca, V. and Wehrheim, P.** 2024. *Bioeconomy globalization: Recent trends and drivers of national programs and policies A report by the International Advisory Council on Global Bioeconomy (IACGB).* www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/52440fb0-f35d-11ee-9ed1-dead53a91d31/current/document/Global_Bioeconomy_-_April_2024_IACGB.pdf and **Italy (Presidency of Council of Ministers).** 2019. *Italian Bioeconomy Strategy (BIT II) – A new Bioeconomy strategy for a sustainable.* https://cnbbsv.palazzochigi.it/media/1953/bit-ii-2019-en.pdf

Public-private partnerships can play a key role in facilitating the transfer of knowledge and disseminating technologies (Box 3). By bridging the gap between local producers and market actors, these partnerships enable small-scale producers to gain access to markets and secure fair prices for their products. Benefit-sharing agreements, such as those seen in the "From Farmer to Pharma" challenge in South Africa (Box 5), demonstrate the potential for mutually beneficial collaborations between communities and private enterprises. Similarly, the Malaysian Government's Bioeconomy Community Development Programme utilizes a contract farming mechanism that ensures farmers and producer associations have guaranteed buyback agreements for their produce. This creates additional sources of income and provides a steady supply of raw materials for bio-industries. Through this programme, rural communities are connected with local bio-industries, and farmers receive training and technological support from these companies.

The bioeconomy has been recognized as offering opportunities for sustainable planning, development, innovation, and employment in urban areas. In 2021, 56 percent of the world's population lived in urban areas, and the percentage is expected to reach almost 70 percent by 2050 (IRP, 2018). Urban material consumption is also projected to more than double by 2050 (Yang and Yang, 2022). In response, concepts like "green cities", "bio-cities", and "urban bioeconomy" are gaining traction (Box 4). Costa Rica, Italy, Ireland, Japan and other countries that are incorporating the bioeconomy into urban planning are promoting "bio-cities". The use of green infrastructures and bio-based construction materials (e.g. engineered wood or alternative materials) is being promoted to lower carbon emissions and reduce waste in construction. Other common activities include enhancing urban ecosystem services, undertaking the bioremediation of degraded areas, and providing nature-based recreational activities. Managing urban biowaste through composting or other biological processes (e.g. insect-based systems), can produce agricultural inputs for urban farming, which can lead to cleaner cities and generate jobs. Alternative energy sources (e.g. biogas and biomass) can diversify urban energy, improve energy security, and strengthen resilience. Bioeconomy-driven innovation and entrepreneurship can also stimulate economic growth and create jobs in urban areas. Start-ups and research institutions in biotechnology and bioinformatics generally lead technological progress and attract investments. However, the urban aspect of bioeconomy is relatively under-researched. There is a need for more studies to understand its full potential and implications (ibid.).

Trade-offs in biomass use do not only have an impact within countries, but also affect international trade relations. From a global perspective, it is important to consider how these trade dynamics affect other countries' abilities to develop a sustainable bioeconomy. The expected rise in demand for biomass in the European Union, for example, would mean an increase in biomass imports from other parts of the world, since it has been estimated that the European Union is close to maximum productivity for its available land and is a net-importer of biomass already (Material Economics, 2021; Backhouse *et al.*, 2021). The extraction of biomass (raw materials) for processing to enhance the development of the bioeconomy in one region, means this biomass is not available for processing in the region of origin. Consequently, the country of origin cannot engage in value-adding processes and loses potential sources of additional income. The transition to a bioeconomy runs the risk of exacerbating these unequal international trade relations if inequalities are not properly addressed through governance mechanisms. The relation between international trade and biomass is further complicated by

the effect trade measures have on biomass flows. Trade tariffs, for example, have an impact on the type of products that are being exported. If trade tariffs are higher for processed products, this incentivizes countries to export raw materials rather than processed materials. This affects the development of the bioeconomy, as many by-products are created during the processing stage of the value chain. Hence, trade tariffs affect where value-adding processes take place, and where biomass, which is necessary for the transition to a bioeconomy, is concentrated.

BOX 4. CASE STUDY Greater Tokyo Biocommunity

Biocommunities are places where the idea of using biological resources becomes deeply rooted and embraced by everyone. They act as hubs that both attract global attention and link local communities. This connection facilitates the flow of information, talent, investments, and research, and creates a cycle of growth. By employing various biotechnologies, these communities seek to become sustainable and eco-friendly, promote healthy living for the residents, and attract local and international support.

The Greater Tokyo Biocommunity (GTB), established in 2021, is strengthening the enabling environment for the bioindustry to realize Japan's vision of becoming the world's foremost bioeconomy society by 2030. The GTB, which consists of 45 organizations that include local governments, universities, and research institutes, which participate in the biocommunity programme of the government in 2022. Home to a concentration of large pharmaceutical companies and start-ups, the GTB fosters a thriving research environment and numerous development pipelines. The GTB has made notable progress to advance the bioeconomy, particularly in the pharmaceutical, agriculture, and environmental sectors. Innovation hubs in eight areas in Tokyo facilitate collaboration between industry, academia, and government, and help streamline research into value chains.

Activities include pharmaceutical, medical and agricultural projects, data collection on biomanufacturing, soil conditions, breeding, wooden architecture, microbiomes for food and health and the genome.

The GTB initiative receives significant funding. Approximately USD 3 billion comes from the government and is earmarked for research and start-up support. As of 2022, this funding has been supplemented by USD 2 billion annually from private investments. These investments are directed towards infrastructure development, start-up funding, and initial public offerings (IPOs). An additional USD 1.6 billion has been allocated to support the establishment of 12 biomanufacturing facilities.

This programme contributes to the target proposed in the Japanese bioeconomy strategy (2019) to reach a total market size of USD 840 billion in 2030 from current USD 550 billion (JbaAdmin, 2022).

Source: JbaAdmin. 2022. Greater Tokyo Biocommunity (GTB) incubation facility list has been opened. In: *Greater Tokyo Biocommunity*. [Cited 4 March 2024] https://gtb.jba.or.jp/en/greatertokyobiocommunitygtbincubationfacilitylisthasbeenopened/

2.3. SAFEGUARDING FOOD SECURITY, SUPPORTING VULNERABLE COMMUNITIES AND RAISING CONSUMER AWARENESS

Safeguarding food security and improving nutrition is an objective of most bioeconomy strategies. The bioeconomy can contribute to all dimensions of food security and nutrition by increasing the availability of food; ensuring its accessibility, quality, and safety; and stability of access.

Optimizing land use practices and resource management are crucial to reduce the trade-offs that can put food security at risk. This optimization can include using marginal lands for agriculture and adopting sustainable intensification practices and integrated production systems that combine food and non-food goods. For example, Germany aims to recultivate degraded and unused areas and focuses on the sustainable management of post-mining landscapes. Italy seeks to promote integrated agricultural value chains and restore soil organic matter, particularly in marginal and abandoned lands.

Harnessing biotechnology innovations for more productive, sustainable and resilient agrifood systems is a recurring theme in bioeconomy strategies (See subchapter 2.4 on science, technology and innovation). China, for example, is integrating biotechnology into farming by using antibiotic alternatives and animal genetic engineering vaccines. Italy has established breeding programmes based on genomics and precision phenotyping to improve the resilience, ecological compatibility, and the robustness of the aquatic species. Biotechnology is discussed in relation to food security in the South African strategy (See Subchapter 2.4 "Science, technology and innovation to accelerate the development of a sustainable bioeconomy").

Several countries stress the role of new bioprocesses and production methods for new food sources and food ingredients that enhance food security and nutrition. Finland focuses on plant-based and synthetic food, Japan and Thailand on functional foods, The East African Community on novel food and feed that can improve rural livelihoods and food security, Namibia on indigenous products, and Estonia on novel aquatic foods sourced from the blue bioeconomy.

Many countries are enhancing food security by maximizing existing resources, making use of agricultural residues and minimizing food loss and waste throughout all stages of production, distribution, and consumption. Activities in this area include adopting sustainable farming techniques that minimize pre-harvest losses and optimize agricultural inputs, such as precision farming, integrated pest management and soil conservation methods. South Africa has highlighted the key role agricultural processing plays in reducing post-harvest losses, extending shelf life, and improving the quality and safety of foods.

Many countries have recognized the importance of supporting small-scale agricultural producers, Indigenous Peoples, and other vulnerable stakeholders, as these groups are often the guardians of natural resources. A well-designed sustainable bioeconomy strategy can help resolve the paradox observed in many low- and middle-income countries, where rural communities possess abundant natural and biological resources yet experience low monetary incomes, do not have access to infrastructure, markets and technologies, and experience higher poverty levels. Building a sustainable bioeconomy is an opportunity to promote rural development and establish new value chains that can alleviate poverty, increase resilience, diversify income, and create green jobs. However, appropriate domestic and international policy

measures are essential. By encouraging transparency, accountability, and collaboration at all stages of the value chain, good governance mechanisms can create an enabling environment where the bioeconomy can provide benefits to local communities. This involves establishing regulations that uphold labour standards, support fair trade practices, establish clear and fair property rights, and other measures that encourage sustainable resource management. It also requires strong partnerships between governments, businesses, and communities to co-create solutions that address the unique challenges and opportunities within each local context.

Indigenous Peoples and local communities often have extensive knowledge of local biological resources and processes. This expertise positions them as key contributors for optimizing the use of local resources and adding value to bio-based products within the bioeconomy. Some bioeconomy strategies seek to connect innovation with traditional knowledge. However, for this relationship to be truly beneficial, it must be reciprocal. Traditional knowledge can provide valuable insights that can complement and inform innovations in biological science, but it is crucial to ensure that the resulting benefits are shared equitably and inclusively (Box 5). In Malaysia, bio-based social innovations have been employed to benefit Indigenous Peoples and rural communities. Colombia is developing a regulatory framework for the equitable use of traditional, ancestral, and local knowledge in the sustainable use of biodiversity and ecosystem services. Italy works to preserve and valorize traditional knowledge and connecting it with the ecological and socio-economic value of agriculture and forestry systems through the transfer of good practices to young farmers and entrepreneurs. Respecting the rights of Indigenous Peoples to self-determination, as well as the use and traditional management of their territories, is a priority for Brazil. Namibia is conducting comprehensive training on access and benefit sharing procedures. Ensuring inclusivity and equitable distribution of benefits begins with integrating these principles into the formulation of the strategies. It is essential to establish mechanisms that ensure all the diverse stakeholders in bioeconomy initiatives are involved in the design and implementation of these initiatives. Through participatory processes, local communities can contribute their insights and expertise, enrich the innovation process, and ensure that proposals are contextually appropriate. Specifically, to realize the potential of the bioeconomy in rural areas, greater attention must be paid to the structural inequalities and high levels of poverty associated with rural livelihoods in low- and middle-income countries.

Providing opportunities for training and capacity building in biomass processing can empower communities and local farmers to take ownership of value-adding activities. In their bioeconomy strategies, Colombia and Italy recognize that enhancing education and skills of farmers, foresters and other stakeholders in the rural bioeconomy is essential for the implementation of sustainable productive activities. It is also crucial to guarantee that these stakeholders have access to credit and financial services and technical support when implementing public policies and programmes. Incentives for sustainable production and consumption can include mechanisms such as price subsidies that are integrated into national social protection systems. For example, Brazil's Minimum Price Policy Warranty for Socio-Biodiversity Products (PGPM-Bio) offers subsidies to small-scale producers when their products are sold below the minimum price set by the Federal Government. This policy generates income for families whose livelihoods depend on natural resources and contributes to the preservation of local ecosystems and the maintenance of forests (Brazil, 2023b).

BOX 5. CASE STUDY **Indigenous Knowledge in South Africa and access and benefit sharing**

Bioprospecting, which can lead to the discovery of new products derived from plants, seaweed, and other biological resources, is important for the development of the bioeconomy. South Africa's bioeconomy and biodiversity strategies promote the commercial use of national plant resources and related indigenous or traditional knowledge to capitalize on natural biodiversity. They also support the application of biotechnologies to create a viable national bioeconomy and enhance the role of indigenous crops in food security. For example, the national target set in South Africa's National Bioeconomy Strategy is to replace up to 25 percent of pharmaceutical imports within a decade.

The country has several programmes that engage in the equitable exploration and sound exploitation of biological resources (sustainable bioprospecting) in ways that have no negative impact on other species and could be replicated as they conform to the Protocols of the Convention on Biological Diversity. International partnerships were sought to connect global funding and technical expertise to local innovators.

Indigenous plants can be used in many products (e.g. nutraceuticals, food additives, flavours, fragrances, biopesticides). A remarkable example involves the wild harvesting of rooibos (*Aspalathus linearis*) in South Africa, which is currently exported to more than 30 countries around the world. This activity originated from the traditional practices of indigenous San and Khoi communities and other local groups, which crucially contributed to the development of the rooibos industry. In 2019, an access and benefit sharing agreement for rooibos was reached between the rooibos industry and the South African San Council and the National Khoi-San Council. These councils each receive 50 percent of the 1.5 percent share of the farm gate price of rooibos in the form of an annual levy, excluding the value-added tax (Wynberg, 2017).

Source: **South Africa (DST: Department of Science and Technology).** 2013. *The Bio-economy Strategy*. www.gov.za/sites/default/files/gcis_document/201409/bioeconomy-strategya.pdf and **Wynberg, R.** 2017. Making sense of access and benefit sharing in the rooibos industry: Towards a holistic, just and sustainable framing. *South African Journal of Botany* 110: 39-51. https://doi.org/10.1016/j.sajb.2016.09.015

Gender- and youth-inclusive approaches must be integrated in bioeconomy development to ensure equal contribution to, participation in, and benefit from bioeconomy activities. By recognizing the value of women's knowledge, experiences, and traditional practices, and by offering them necessary training and employment opportunities, the bioeconomy can foster gender equality and empower women. An example is the Zanzibar Seaweed Cluster Initiative in the United Republic of Tanzania, which targets women farmers and supports them in seaweed production, processing and marketing, to make them more financially independent and increase their participation in economic decision-making processes (FAO, 2018a).

Empowering young people is an essential yet often overlooked theme in bioeconomy strategies. Specialized knowledge and skills are needed for the development of a bioeconomy. To

build such a talent pool, many countries are planning to provide educational opportunities, specialized courses and professional training, and increase the connections between universities and bio-based industries. However, few strategies explicitly target support to young people in the agrifood sector, except for Italy, who supports young land managers and entrepreneurs to adopt good practices in the agrifood and forest-wood sectors in less developed Italian regions, and Brazil, who encourages the inclusion of women and young people in the bioeconomy. In summary, gender and youth, as well as connections that bridge rural and urban areas, are often overlooked in the development of the bioeconomy. There is a pressing need to integrate these dimensions more effectively into bioeconomy development (Dietershagen and Bammann, 2023).

Many bioeconomy strategies recognize the need to integrate supply-side measures with demand-side measures. Focus is placed on improving consumer access to sustainable bio-based products and creating positive attitudes and preferences for these products. Nearly all bioeconomy strategies incorporate campaigns to raise awareness about the environmental, social, and economic advantages of the bioeconomy. This is often done through training, education, and specialized university programmes. Labels, certificates, and quality marks are often used to guide consumers towards more sustainable and conscious purchasing choices. Measures for green procurement, which encourage the public and private sectors to favour goods and services with smaller environmental footprints and higher social responsibility standards, are also common. A notable example is the BioPreferred Program in the United States, which supports the use of bio-based products through a government procurement programme and a voluntary certification and labelling scheme. Since its inception in 2011, this programme has certified and labelled nearly 9 000 bio-based products (as of 2023) (Boldt, 2023). Austria, Brazil, Costa Rica, France, Ireland, Italy, Latvia, Malaysia, Namibia, South Africa, Spain, the United States and the Nordic region have all recognized the importance of shaping public perception of the benefits of the bioeconomy. Costa Rica and the Nordic region explicitly aim to influence social attitudes as part of their bioeconomy goals.

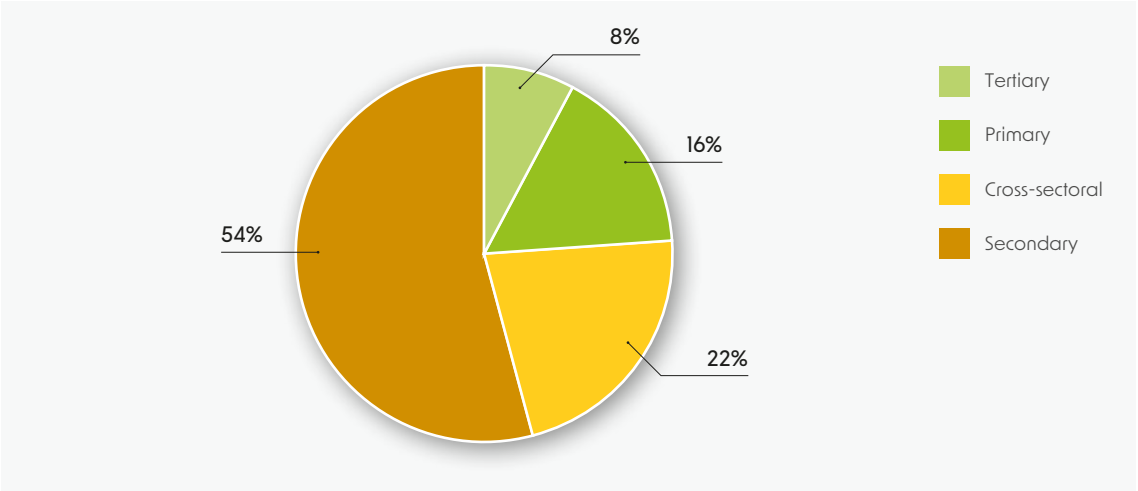
2.4 SCIENCE, TECHNOLOGY AND INNOVATION TO ACCELERATE THE DEVELOPMENT OF A SUSTAINABLE BIOECONOMY

The 2021 United Nations Food Systems Summit, convened by the UN Secretary-General, emphasized the importance of transforming agrifood systems so that they are healthier, more sustainable, and equitable. This is seen as essential for achieving the SDGs and recovering from the COVID-19 pandemic. The Summit highlighted the need for countries, especially in the Global South, to build capacities in biosciences and biotechnology with support from development partners to ensure inclusive progress. Currently however, the countries that most need science and innovation are not those with strategic plans to advance it (Von Braun *et al.*, 2023). The bioeconomy, which integrates various systems, disciplines, and sectors, relies on bioscience and biotechnology for producing and managing goods, processes, services, and energy to deliver economic, environmental, and social benefits. However, because bioeconomy opportunities depend on science, technology and innovation, the disparity between high-income and low- and middle-income countries may increase. To narrow the gap, international cooperation is critical. A growing number of low- and middle-income countries are formulating science policies, but they are often unable to implement them successfully often because of the inadequate integration of these policies into the national development plans and budgets (Von Braun, 2015).

Science, technology, and innovation are pivotal in driving the bioeconomy and are widely incorporated into bioeconomy strategies, which are often led by ministries responsible for science and technology. All strategies place a priority on innovation. About one-third of the actions in these strategies are closely linked to enhancing technology and innovation, especially in the secondary sector (54 percent), which includes bio-based industries. Sixteen percent of the measures focus on the primary sector, and 22 percent are intersectoral (Figures 2 and 3).

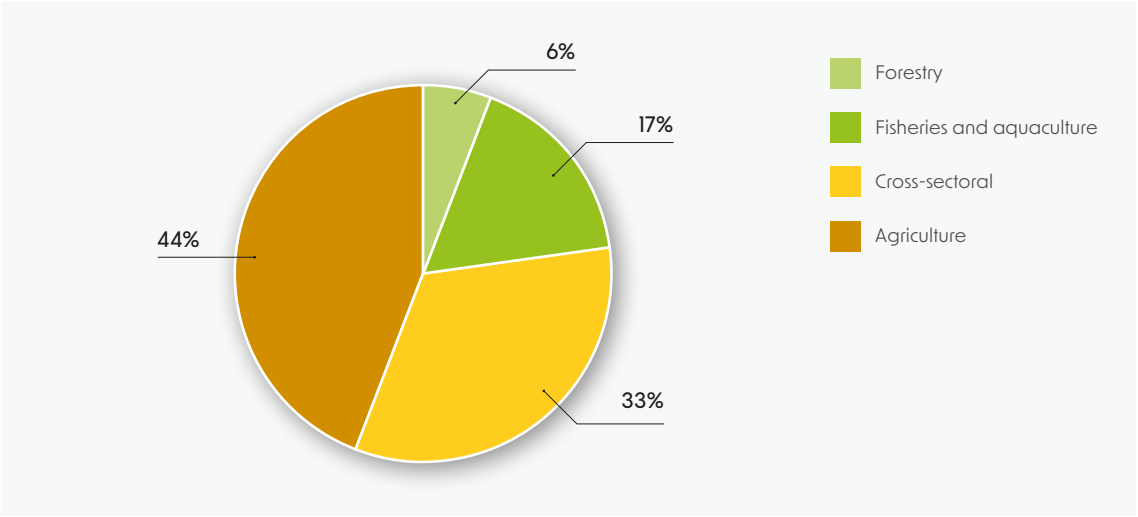
In agriculture, forestry, fisheries and aquaculture, technology and innovation are harnessed mainly for fostering sustainable, efficient and resilient agrifood systems. Countries are enhancing productivity and quality by promoting the use of innovative technologies, such as genome selection (Box 6), synthetic biology, and artificial intelligence in breeding programmes. There is also a focus on developing resilient agricultural practices, harnessing biotechnology to improve animal and plant resilience to stresses, and implementing molecular techniques for crop and livestock improvement (e.g. breeding, diagnostics, and vaccine development). Alternative animal feeds, feed additives, and circular practices (e.g. recycling manure for use in fertilizers or biofuels) are seen as options for reducing the reliance on unsustainable agricultural inputs and mitigating their environmental impacts. Animal by-products are being accorded greater value as they can be used to produce a range of innovative products (e.g. cosmetics to composite materials). Countries are also exploring innovative methods and business models for harvesting and utilizing all parts of cultivated plants and improving harvest and postharvest technologies. Actions in this area include establishing hubs for agricultural innovation, improving agricultural processing to reduce post-harvest losses, and investing in high-value skills and capacities for agricultural innovation. For bio-based agricultural inputs, there is a growing interest in the development of biological agents derived from agricultural waste, natural agricultural biomedicines, precision multi-target biological pesticides, and biological products that improve the soil. Understanding the strategic role of microorganisms in enhancing the resilience and productivity of plants, animals, and ecosystems is an emerging priority for many countries.

FIGURE 2. Technology and innovation across economic sectors in bioeconomy dedicated strategies



Source: **FAO.** 2024. *Dashboard on bioeconomy strategies and related actions for sustainable development.* [online]. Rome. [Cited 4 June 2024]. www.fao.org/in-action/sustainable-and-circular-bioeconomy/dashboard/en/

FIGURE 3. Integration of technology and innovation within the primary sector activities in bioeconomy dedicated strategies



Source: **FAO.** 2024. *Dashboard on bioeconomy strategies and related actions for sustainable development.* [online]. Rome. [Cited 4 June 2024]. www.fao.org/in-action/sustainable-and-circular-bioeconomy/dashboard/en/

Countries are focusing on improving forestry practices through the digitization and management of data at national and regional levels. This includes the use of drones, remote sensing technologies, and artificial intelligence to support management planning and value chain logistics. Countries are also strengthening production capacities and enhancing the resilience of forests by establishing genetic improvement programmes that use planting materials that are better adapted to the expected impacts of climate change in regeneration and afforestation efforts and conducting studies to identify suitable species and methods for resin extraction. In wood production, countries are also adopting new technologies (e.g. more efficient logging and harvesting methods) to increase recovery rates (FAO, 2024c; Roshetko *et al*, 2022).

Countries are prioritizing innovative and technological advancements in fisheries and aquaculture. They are working to deploy advanced aquaculture technologies (e.g., water recirculation plants) and promote collaboration between sectors to accelerate the development of sustainable operating models. The implementation of breeding programmes leveraging genomic data is being investigated as a strategy for improving the resilience of aquatic species (Friedman *et al*, 2022). Countries are also working on integrating monitoring and control systems using information and communication technologies, and data analysis to combat illegal fishing. National efforts also focus on integrating marine energy technologies with aquaculture; pursuing ecosystem-based management of fisheries; and investing in innovative practices, such as smart hatchery systems. Sustainable aquaculture is promoted through programmes emphasizing industrial symbiosis and the cascading use of by-products and effluents. This includes the expansion of multitrophic aquaculture for marine sustainability and resource recovery (FAO, 2024d).

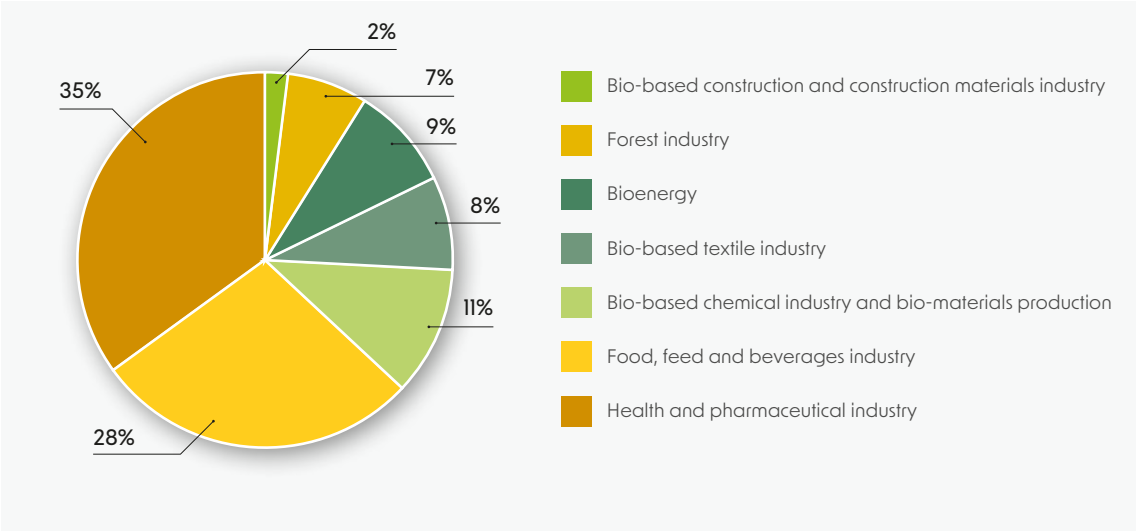
BOX 6. CASE STUDY **Induced genetic variety and genomics technologies on rice and soybean**

The production of rice, a major staple crop in Viet Nam, was constrained by low productivity owing in large part to the cultivation of unimproved rice varieties. The domestic production of soybean was also insufficient to meet consumer demand, which necessitated the unsustainable expenditure of foreign exchange to import soybean. The exposure of the seeds or other planting materials to physical irradiation or chemical mutagens can induce novel genetic variation, which have the potential to be used in the development of superior crop varieties. Precise selection processes, sometimes with the application of molecular markers, and a streamlined breeding programme can enhance the efficiency of the development of improved varieties using induced mutagenesis. Since the 1980s, the practice of mutation breeding in Viet Nam has led to the development of 80 commercialized mutant crop varieties, including 54 of rice and 16 of soybean. The Agricultural Genetics Institute of Viet Nam is a leader in mutation breeding in the country and has commercialized 19 mutant varieties of rice and 13 of soybean. The earliest released rice mutant variety (DT10) has been cultivated on 2.4 million ha since its release, which has contributed to an increased income of USD 536 million, benefiting 3 million farmers. Included among the most recently released rice mutant varieties was the DT80 for which presence of the Saltol quantitative trait locus was confirmed through marker-assisted selection. This variety, which can withstand saline soils, has been cultivated on a cumulative area of 15 000 ha since its release in 2019. It produces an average yield of 6 to 7 tonnes per hectare and generates increased earnings of USD 330 per hectare compared to the parent variety. Mutation breeding is also routinely applied to the genetic improvement of soybean. Over half of the area under soybean cultivation in the country is planted with mutant varieties. High-yielding, short duration soybean varieties are sought after. The mutant variety (DT 2008) is cultivated by about 1.5 million farmers. There is an increasing demand for black soybean for food processing, and currently only one black-seeded variety is grown in Viet Nam (DT 215). Research is being done to determine the molecular basis for the trait and facilitate molecular breeding (Sivasankar and Ham, 2023).

Source: **Sivasankar, S. and Ham, L.H.** 2023. Impact of induced genetic variation and genomics technologies on rice and soybean productivity in Viet Nam. In: Ruane, J., Mba, C., Boettcher, P., Koskela, J., Mair, G. and Ramasamy, S., eds. 2023. *Case studies of the use of agricultural biotechnologies to meet the needs of smallholders in developing countries*. Rome, FAO. https://doi.org/10.4060/cc8940en

Technology and innovation in bio-based industries and biorefineries is also being deployed in the secondary sector (Figure 4). Green chemistry to produce bio-based plastics is a growing area, including the production of advanced biomolecules and high value bioproducts, the development of enzymatic processes that promote biomass conversion, and the use of synthetic biology and gene editing. In the forestry industry, digitization, data management, streamlined wood processing and manufacturing for supply chain optimization are all being explored. The forestry industry is also moving to new sectors through the development of value-added innovative forest products (e.g. wood-based materials) and making textiles or cellulose gum (a food ingredient) from trees. Innovations in the sector include wood modification technologies,

FIGURE 4. Integration of technology and innovation within the secondary sector industries in bioeconomy dedicated strategies



Source: FAO. 2024. *Dashboard on bioeconomy strategies and related actions for sustainable development*. [online]. Rome. [Cited 4 June 2024]. www.fao.org/in-action/sustainable-and-circular-bioeconomy/dashboard/en/

digitalized wood procurement processes, and the development of new packaging materials (FAO, 2024c; Roshetko *et al*, 2022). The energy sector works on bioeconomy innovations for biomass power generation and advanced biofuels, as well as enhancing energy efficiency. Initiatives also focus on biomass conversion technologies, bioenergy hybrid pilots, combined heat and power systems, and biological carbon dioxide capture and utilization processes to reduce carbon emissions. Innovations in the health sector include technologies for the genetic detection and prevention of diseases and the development of advanced diagnostic techniques and biopharmaceuticals. Biopharmaceuticals make use of traditional knowledge and new technologies to create pharmaceuticals from biological materials. There is a strong emphasis on personalized medicine, regenerative therapies, and improving clinical care. The development of the bioeconomy in the food, feed, and beverages industry includes creating innovative food products and enhancing supply chain efficiency. Innovations cover the use of advanced technologies for food safety, rapid detection tools, and eco-friendly packaging solutions. An emphasis is also being placed on exploiting microorganisms for sustainable food production; researching microbiomes for precision nutrition; creating alternatives to animal source foods using proteins from plants or animal cells, or through fermentation; and developing functional foods. Trends in the bio-based textile industry encompass developing sustainable fibres from waste materials, implementing ecodesign principles, and utilizing digital tracking tools for transparency in the supply chains. Efforts also include the development of platforms and databases to support the implementation of recycling and industrial symbiosis processes. Bioeconomy innovations in the bio-based construction and construction materials sector focus on digitization, research and development in fibre-based insulation materials, the use of wood or agricultural residues in construction, and climate-smart forestry and large-scale wood construction to maximize the use of bioresources. Innovations target low-carbon, climate-smart construction that use a variety of different renewable materials (FAO, 2024c; Roshetko *et al*, 2022).

The microbiome, which connects food and health to the bioeconomy, is an expanding and increasingly important bioeconomy area of interest (Callens *et al.*, 2022). Science, technology, and innovation related to the microbiome can lead to healthier diets, reduce malnutrition and waste, and foster innovative business models. Microbiome research, which has broad applications in plant production, animal feed and human health, can contribute to combating obesity and the noncommunicable diseases associated with it. Integrated research and policy approaches are crucial for addressing the complex connections between economic development, food production, livelihoods, ecosystem integrity, resilience, and health. Several countries are incorporating microbiome research into their bioeconomy development. For example, Colombia is focusing on characterizing population groups for better disease prognosis, prevention, diagnosis, and treatment, and is looking at the relationship between the environment, individual microbiomes, and nutrition. Italy is conducting research into the gut microbiome to provide information to consumers about the importance of healthy diets.

2.5 BIOSAFETY AND BIOSECURITY

Bioeconomy innovations should be deployed in such a way that they do not negatively impact human and animal health nor the environment. According to FAO, biosecurity is a set of measures and practices designed to protect against the introduction and spread of infectious diseases, pathogens, or harmful biological agents within a particular environment, whether they affect humans, animals, or plants (FAO, 2016). Biosafety, within the biosecurity framework, refers to safe use of new biotechnologies in the holistic management of biological risks associated with food and agriculture.

Both concepts are closely connected to the One Health approach. One Health is "a collaborative, multidisciplinary, and multisectoral approach that can address urgent, ongoing, or potential health threats at the human-animal-environment interface at subnational, national, global, and regional levels" (WHO, 2023). For instance, One Health plays a central role in addressing zoonotic diseases like COVID-19, antimicrobial resistance and other major global challenges, building on the growing understanding of microorganisms, their functions, and how they interact. With radical improvements in biosciences and biotechnologies (e.g. DNA sequencing and bioinformatics) it is now possible to study microorganisms, most of which had been previously unknown, in their native environments. Sustainable bioeconomy development can provide solutions to reduce biological risks associated with the use of pesticides, fertilizers and other agricultural inputs by creating non-toxic bio-based alternatives to agrochemicals. It can also protect water, soil and land from threats posed by harmful chemicals and pathogens through bioremediation and other bioeconomy practices that can restore ecosystems and regenerate biodiversity.

Biosafety and biosecurity have been identified in the national and regional bioeconomy strategies as an important area of work (Dietz *et al.*, 2024). The United States included both biosafety and biosecurity in its bioeconomy strategy document, highlighting biological risk management as one crucial element. The aim is to enhance biological risk management in biotechnology research and development, including investments in biosafety and biosecurity (United States of America, 2022). China, in its most recent bioeconomy policy, the Chinese 14th five-year plan for the bioeconomy, identifies four key areas of development, one of which

concerns national biosecurity risk prevention (China, 2021). In South Africa, a biosecurity hub has been launched to protect the country from new invading sanitary and phytosanitary threats and provide information and research services to both the public and private sectors (Maharaj, 2022).

2.6 INTERSECTORAL POLICIES AND THE ENABLING ENVIRONMENT FOR A SUSTAINABLE BIOECONOMY

It is widely acknowledged that at the current rate of consumption it is not possible to supply all biomass necessary to replace fossil fuels or other unsustainable resources across all sectors without compromising food security (Von Braun, 2018; Backhouse *et al.*, 2021). Optimizing the allocation of finite resources (such as land, water, and biomass) among various sectors while ensuring efficiency, equity, and sustainability, which is the main challenge for the bioeconomy, requires a systems approach. Given the constraints on biomass availability and the fact that technological advancements are not accessible to everyone, trade-offs are an unavoidable part of bioeconomy development. This underscores the importance of good governance mechanisms that guarantee intersectoral policy coherence, foster investment and innovation, oversee and monitor the implementation of bioeconomy strategies towards national and international sustainability targets, and promote international exchange and cooperation. International cooperation may involve technology transfers, cross-borders research initiatives, or increased international trade (Bojić, Clark and Urban, 2022; GBS, 2020). Monitoring the sustainability of the bioeconomy is a fundamental aspect of any bioeconomy strategy and is addressed in the next section.

Most countries prioritize the establishment of institutions dedicated to the bioeconomy or ad-hoc governance mechanisms, to ensure that the development of the bioeconomy fosters synergies and reduces trade-offs between biomass uses in different sectors. Bioeconomy governance mechanisms take different forms in different strategies. For example, Spain has established a "bioeconomy observatory", whereas Portugal has set up a "National Council for the Sustainable Bioeconomy", and Namibia a "Bioeconomy Multi-sectoral Working Group" (BMWG), involving representatives from several ministries, academia, private sector and civil society. The ministries that are involved in developing bioeconomy strategies also vary widely across countries. Many countries have shown intersectoral collaboration involving multiple ministries. In Finland, eight different ministries are involved in bioeconomy development. This indicates a recognition that bioeconomy is multidisciplinary in nature, encompassing aspects of agriculture, industry, environment, economics, science, technology, and innovation. Most strategies are led by ministries dedicated to agriculture, but ministries dedicated to science, technology, and innovation are also commonly involved in bioeconomy development. In the United States, for example, it is the result of an executive order from the President, and in Japan it is led by the Cabinet Office. This reflects strong government commitment to advancing the bioeconomy agenda. It is interesting to note that bioeconomy governance can also have a local dimension. In addition to national and regional strategies, various sub-national entities (e.g. territories or municipalities) are also developing bioeconomy initiatives. This can represent a bottom-up approach to bioeconomy development, as is the case with the Bioeconomy State Strategy of the State of Pará in Brazil or respond to an overarching national bioeconomy strategy and serve as an effective mechanism for localized implementation. In the European Union, around 30 sub-national territories have developed their own bioeconomy strategies (EC, 2019).

The bioeconomy development at a national level often has important cross-border implications highlighting the limitations of relying solely on national governance (Proestou, Schulz and Feindt, 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). Enhanced intergovernmental cooperation and coordination are crucial. This could include reaching consensus on globally agreed principles of bioeconomy.

While bioeconomy approaches are context-specific and reflect varying national and regional capabilities and circumstances, they share several common objectives aimed at tackling interconnected challenges like food security, climate change, biodiversity loss, pollution, and sustainable development (Gomez San Juan and Bogdanski, 2021). The diversity in approaches could be seen as an obstacle, instead different and complementary ways to achieve these common objectives should be embraced withing a global bioeconomy framework.

Effective global governance of the bioeconomy requires coordination across countries, multiple sectors, and different levels of government. Currently, such coordination mechanisms are still emerging (Lang, 2022), and there is a recognized need to establish mechanisms that facilitate cooperation among public and private entities at multiple levels (global, regional, national, and sub-national). Additionally, the transboundary impacts and risks of transitioning to a bioeconomy necessitate international cooperation (Von Braun and Birner, 2016). To achieve international

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harmonization, it is essential to co-design more robust governance tools and comprehensive monitoring systems (Gardossi, 2023). The absence of a unified global framework for promoting and regulating the bioeconomy, coupled with the overlapping institutional arrangements of existing global mechanisms, remains a significant impediment. This lack of cohesion hinders the efforts of governments, the private sector, academia, and other stakeholders in realizing the transformative potential of the bioeconomy (Dietz *et al.*, 2024).

Among some prominent global bioeconomy partnerships are the International Advisory Council on Global Bioeconomy (IACGB), the International Bioeconomy Forum (IBF), the Circular Bioeconomy Alliance (CBA), the World Bioeconomy Forum (WBEF). There are also groups and platforms at a regional level, which enhance the global visibility of low- and middle-income countries, Small Island Developing States (SIDS) and less advantaged countries, and draw greater attention to their needs (Bößner, Johnson and Shawoo, 2021). While some members participate in multiple international platforms, there is a lack of coherence and coordination among these fora and their alignment with the existing sustainable development frameworks and multilateral environmental agreements.

The International Sustainable Bioeconomy Working Group (ISBWG), which is led by FAO, supports countries in building a sustainable bioeconomy. It is composed of around 35 members of a broad range of expertise and backgrounds, from policy to research, private sector, civil society and international organizations, from all five continents. This multi-stakeholder expert group serves as an informal platform for sharing knowledge and experiences about sustainable bioeconomy development. One of its functions is to act as an advisory body to the FAO bioeconomy programme.

The ISBWG is also a platform for South-South and Triangular cooperation in the bio-based sectors. In general, countries in the Global South have extensive knowledge and experience in the production of food, feed, fibre, biopharmaceuticals and other bioproducts. The ISBWG offers a unique opportunity for countries to gain knowledge and share their experiences in the development of strategies and programmes and enhance stakeholder coordination.

The most recent development—the establishment of the G20 Initiative on Bioeconomy (GIB) under Brazil's presidency—will foster further international dialogue and action on the subject (G20 Brazil, 2024). The GIB's work is based on discussions about the concept of the bioeconomy, its current state of development, and its future potential. Its activities are structured around three themes: (i) research, development, and innovation for the bioeconomy; (ii) the sustainable use of biodiversity for the bioeconomy; and (iii) bioeconomy as an enabler for sustainable development. The GIB's main deliverable is a set of agreed High-Level Principles on Bioeconomy. These principles will be an integral part of the Rio Declaration, which is to be adopted by the G20 Heads of State at the end of Brazil's presidency of the Group.

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).

Chapter 3. Monitoring the achievement of the sustainability objectives of bioeconomy strategies

Many national and regional strategies include monitoring systems and measurement tools to track their bioeconomy development and sustainability goals. However, there is a need to establish global standards to measure sustainable development goals achievements on the bioeconomy (IACGB, 2023).

FAO normative work is expanding to include various methods for assessing the sustainability of bioeconomies. The Organization's monitoring efforts extend beyond quantifying the potential size of a country's bioeconomy to focus on broader issues related to measuring sustainability and the transformative impact of bioeconomy strategies. Box 7 outlines a timeline of FAO's work on the matter since 2016 and summarizes the different sources that inform FAO's approach to bioeconomy monitoring. FAO also has a number of tools, analysis methodologies, projects and databases, including those using geographic information systems (GIS), that can be used for holistic bioeconomy assessments.[9] These can be used, for example, to detect where crop residues and organic waste are being burnt and where they are contributing to local pollution.

There are two main types of bioeconomy assessments: *ex-ante* assessments, which integrate sustainability into the planning of bioeconomy interventions (e.g. assessments of the potential uses of biomass and crop residues without affecting soil health, or cost-benefit analyses of bio-based innovations and technologies); and *ex-post* assessments, which assess impacts, evaluate outcomes, or monitor progress (e.g. assessments of global biomass flows, the sustainability of value chains, the performance of good practices, or environmental footprints).

9 For instance, see the different tools, methodologies and analysis from the FAO Statistic Divisions www.fao.org/about/who-we-are/departments/statistics-division

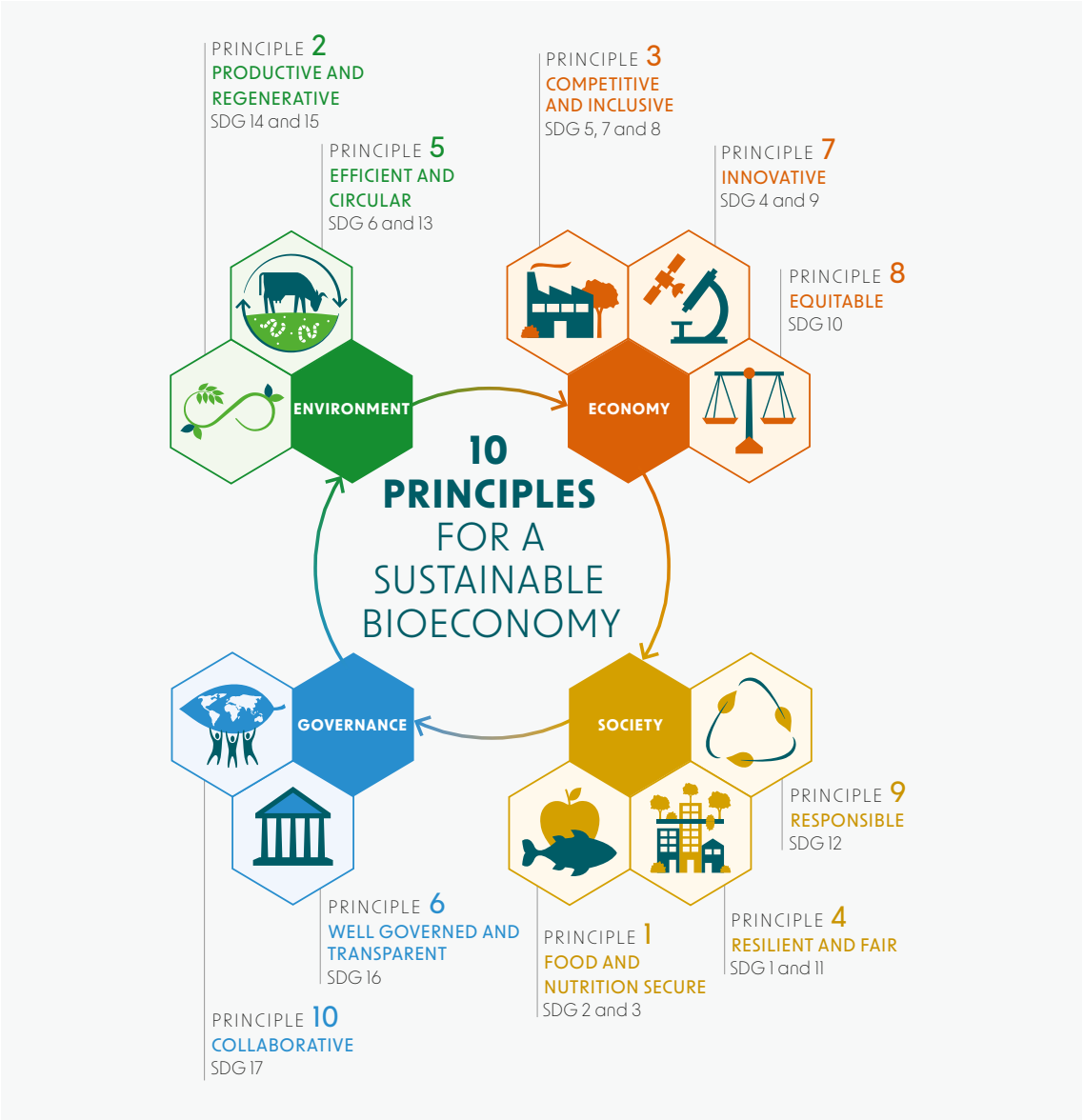
BOX 7. FAO's journey towards a holistic bioeconomy indicators framework

- 2016 – A first analysis of the sustainability of bioeconomy strategies and the publication of *An Overview on How Sustainability is Addressed in Official Bioeconomy Strategies at International, National and Regional Levels* (Dubois and Gomez San Juan, 2016). This publication provides an assessment of overarching social, economic, and environmental sustainability criteria, competition with food.
- 2018 – Publication of *Assessing the Contribution of Bioeconomy to the Total Economy: A Review of National Frameworks* (Bracco *et al.*, 2018). This publication finds that measuring the contribution of the bioeconomy to the total economy is not enough to show its transformational potential.
- 2019 – Publication of *Indicators to monitor and evaluate the sustainability of bioeconomy* (Bracco *et al.*, 2019a). This publication finds that a wide range of available criteria and methodologies, including good practice proxies are easy ways to start the process of monitoring at two main levels: territorial and value chains.
- 2019 – Follow-up paper on the value chain monitoring and evaluation: *Analysis of Standards, Certifications and Labels for Bio-based Products in the Context of Sustainable Bioeconomy* (Bracco *et al.*, 2019b). The key finding of this paper is that at the product level, criteria deal almost exclusively with circularity.
- 2021 – Publication of the *10 Aspirational Principles and 24 Criteria for a sustainable bioeconomy* (FAO, 2021) in collaboration with the ISBWG, which provides the foundation for FAO guidance documents on developing a sustainable bioeconomy.
- 2021 – Follow-up paper on SDG monitoring and evaluation: *Linking the bioeconomy to the 2030 sustainable development agenda: Can SDG indicators be used to monitor progress towards a sustainable bioeconomy?* (Calicioglu and Bogdanski, 2021).
- 2021 – Follow-up publication on how to use good practices as proxy indicators: *How to mainstream sustainability and circularity into the bioeconomy?* (Gomez San Juan and Bodganski, 2021).
- 2021 – Follow up publication of the *Guidance note on monitoring the sustainability of the bioeconomy at a country or macro-regional level* (Bogdanski *et al.*, 2021), with 10 steps to guide the development of coherent and holistic monitoring frameworks for the bioeconomy, centred around the 10 Aspirational Principles and Criteria.
- 2023 – Publication of *Monitoring the sustainability of the bioeconomy. Pilot in Uruguay* (Pozo *et al.*, 2023), which provides examples of methodologies and tools that have been used to analyse biomass flows and sustainability in a national context.
- 2024 – Publication of the *Bioeconomy Toolbox* (Gomez San Juan, 2024) to support the design, updating and monitoring of bioeconomy strategies.
- 2024 – Development of the FAO Dashboard on bioeconomy (FAO, 2024) to track bioeconomy strategies and to identify their actions and links connecting the bioeconomy to national targets for climate adaptation and mitigation, biodiversity protection and food systems transformation.

Sources: See References Box 7

The FAO Aspirational Principles and Criteria for a Sustainable Bioeconomy (Figure 5) provide an important framework to guide an inclusive transition to a sustainable economy that supports the achievement of SDGs. They also guide the design of monitoring frameworks for bioeconomy strategies to track the sustainability of the bioeconomy and progress being made to achieve national and regional objectives. These principles, which are central to FAO's work on the bioeconomy, encourage stakeholders to adopt a comprehensive approach that integrates the social, economic, environmental dimensions of sustainability and governance mechanisms. The application of these principles to create effective bioeconomy policies requires tailoring the policies to specific contexts, so that they address potential trade-offs and foster technological, organizational, and social innovation.

FIGURE 5. Principles and Criteria for a Sustainable Bioeconomy



Source: **FAO.** 2021. *Aspirational Principles and Criteria for a Sustainable Bioeconomy*. Rome, FAO. 16 pp. https://openknowledge.fao.org/items/152324b8-6d78-4d55-b61f-274649c8422d

The Aspirational Principles and Criteria have been used to develop holistic monitoring frameworks and sets of indicators and tools that can be used to measure the extent to which strategies are being followed. These metrics, which include indicators that are linked to the SDGs, are used by countries (e.g. Costa Rica[10] and Uruguay[11]), the European Union[12] and by industries and other value chain stakeholders. The development of these principles drew inspiration from the Committee on World Food Security *Principles for Responsible Investment in Agriculture and Food Systems* (RAI) (FAO, WFP and IFAD, 2014).

Box 8 illustrates the diverse approaches countries have taken in establishing monitoring systems within their bioeconomy strategies.

FAO advocates the use of a two-level indicator framework for monitoring the bioeconomy that focuses on territory and value chains. This dual approach allows for a comprehensive assessment of the sustainability of the bioeconomy and its performance across different scales and sectors. A third level of assessment considers investment in technology, which has been receiving greater attention by development banks.

Territorial indicators are designed to capture the impact of the bioeconomy and progress within a specific geographic area (e.g. a country or a macro-region) and ecosystem. These indicators allow for an assessment of the contribution the bioeconomy is making to national and regional economies and its role in sustainable development, environmental protection, and social well-being. They can include data on status of forests, agricultural productivity, and the overall economic contribution of bio-based sectors to the gross domestic product (GDP). They are often derived from national statistics or international databases that provide a macro-level view of the development and sustainability of the bioeconomy. More bioeconomy-specific metrics are needed, for example, indicators that cross over sectors and value chains. These metrics could involve indicators of good practices in mixed landscape, integrated systems and biorefineries, or more broadly innovation in land and biomass management and learning (Bracco *et al.*, 2019a).

Value chain indicators focus on specific bio-based products or services to assess their environmental, social, and economic impacts throughout their life cycle from production and processing to consumption and disposal. This monitoring provides information on the sustainability of individual bio-based products, and their interconnections within a wider value web or industrial ecosystem where different industries and sectors are developed around biomass. The value chain indicators can help identify hotspots of environmental impact, 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 (SFVC) framework that can support the assessment, development, and monitoring of bio-based product value chains. Life-cycle assessment (LCA) methodologies can be used to evaluate the environmental footprint, social implications, and economic viability of bio-based products (Box 9).

10 See https://bioeconomia.go.cr/observatorio/acercaDe.jsf

11 See www.fao.org/documents/card/en/c/cc7309b

12 See https://op.europa.eu/en/publication-detail/-/publication/9be6bf37-3e5e-11ea-ba6e-01aa75ed71a1

BOX 8. 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).

Continues on the next page

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).

Sources: See References Box 8

The scarcity of data about biomass availability and uses, including biowaste, residues, and by-products, poses a significant challenge when it comes to evaluating the sustainability of the bioeconomy. Biological resources include biomass from crop and forest plantations that are used in a range of industries and can be sold or traded, but they also include biological resources that are not accounted for in national statistics or international trade (e.g. crop residues, urban organic waste, indigenous products consumed locally). Also, microorganisms used in industry (e.g. soil microorganisms used by the medical and pharmaceutical industries), are left out in national and global estimates of biomass volumes for processing industries.

BOX 9. Life-cycle assessments

An LCA considers the impacts associated with all stages of a product or service from "cradle to grave" or from "cradle to cradle". A life cycle perspective covers the environmental aspects of the activities, products and services that an Organization can control or influence. Stages in a life cycle include the acquisition of raw materials, design, production, transportation and delivery, use, end-of-life treatment, and final disposal. A growing number of countries are promoting LCAs to monitor new biotechnologies, biomass flows, bio-based products and services, and their economic, ecological, and social impacts (Sala and Castellani, 2019).

When assessing the socio-economic impact of a product using LCAs, it is crucial to consider the geographical location of the production plant. LCAs are applied to all stages of a product, and its territorial governance and main stakeholder groups can have an impact on each stage. Italy as part of its bioeconomy strategy, has developed a set of LCA sustainability indicators that measure, in addition to economic growth, impacts on food security, the sustainability of natural resource use, dependence on non-renewable resources, and climate change adaptation and mitigation.

LCAs using sustainability indicators are being developed to cover the social and economic dimensions of sustainability. However, classic LCAs and other technical and economic analyses are currently more suited for assessing environmental flows and impacts. It's essential to interpret these sustainability indicators correctly to avoid shifting the potential burden of the environmental impacts caused by bioeconomy interventions to the socio-economic sphere, and vice versa.

Source: **Sala, S. and Castellani, V.** 2019. The consumer footprint: Monitoring sustainable development goal 12 with process-based life cycle assessment. *Journal of Cleaner Production, v. 240, 118050*. https://doi.org/10.1016/j.jclepro.2019.118050).

Chapter 4. Bioeconomy at FAO: advancing bioeconomy for sustainable food and agriculture

FAO's work on the bioeconomy began with the final communiqué of the seventh meeting of Ministers of Agriculture, which was held during the 2015 Global Forum for Food and Agriculture. The Global Forum highlighted the urgent need to address sustainability trade-offs in the bioeconomy, and its final communiqué recommended that "FAO continues and intensifies its work on the primacy of food security in bioeconomy and provides information and pertinent policy advice for the benefit of its Members". It also acknowledged that "tangible action and international cooperation are necessary to seize the opportunities provided by sustainable bioeconomy for agriculture and rural development while securing the primacy of food security and nutrition" and that "FAO, in collaboration with other partners, would provide the appropriate platform for this purpose" (GFFA, 2015).

Momentum increased with the formation of the ISBWG in 2016, a multi-stakeholder platform for knowledge exchange and advisory support. With the support of the German Federal Ministry of Food and Agriculture, FAO has implemented the "Towards Sustainable Bioeconomy Guidelines" programme (2017-2023), which has produced guidelines for sustainable bioeconomy strategies and supported countries (e.g. Namibia and Uruguay) in developing their bioeconomies (FAO, 2019). In 2021, the 42nd Session of the FAO Conference elevated "Bioeconomy for sustainable food and agriculture" to one of its 20 PPAs in the FAO Strategic Framework 2022-31 (FAO, 2021b). This decision aligns with the objective of transforming agrifood systems for better production, better nutrition, a better environment, and a better life, leaving no one behind and with the 2030 Agenda for Sustainable Development goals. The PPA "Bioeconomy for sustainable food and agriculture" makes FAO the first and, so far, only UN agency to strategically prioritize bioeconomy. At the 43rd Session of the FAO Conference in 2023, Members emphasized the importance of bioeconomy's role in sustainable agrifood systems and called for further discussions on the subject within FAO's governing bodies and technical committees (FAO, 2023a; FAO, 2023b).

The sections that follow – which correspond to the four pillars of the FAO Strategic Framework: better production, better nutrition, a better environment and a better life – provide an overview of FAO's work under the PPA "Bioeconomy for sustainable food and agriculture", with examples from different countries and contexts.

4.1 THE PROGRAMME PRIORITY AREA ON BIOECONOMY FOR SUSTAINABLE FOOD AND AGRICULTURE

The PPA on bioeconomy is designed to be cross-cutting and encompasses a range of technical areas. This structure ensures that Members receive diverse expertise tailored to their specific needs for bioeconomy development and monitoring.

The PPA on bioeconomy, which falls within the better environment pillar of the FAO Strategic Framework, envisions a bioeconomy that balances economic growth, social welfare, and environmental sustainability. It focuses on advancing the transition to a bioeconomy through evidence-based policies and practices. Anchored in SDG 12 (Responsible consumption and production), PPA BE2 orients FAO contributions to SDG targets 12.2 (improving sustainable resource management), 12.4 (reducing pollution), and 12.5 (minimizing waste generation).

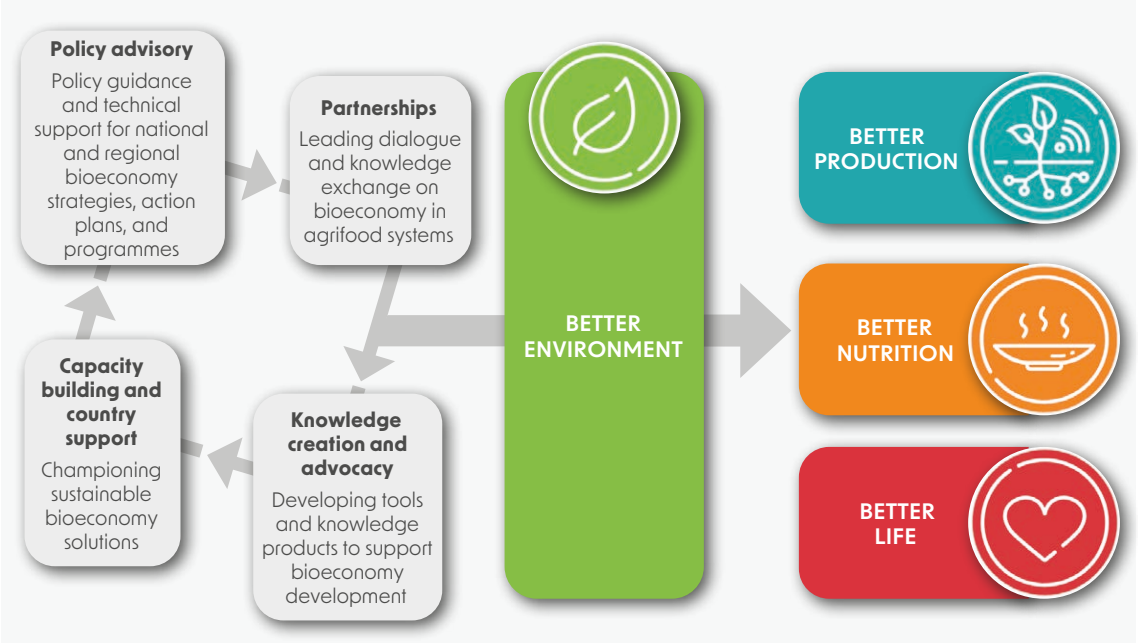
Operationally, PPA BE2 has two main thematic components:

i. facilitating the deployment of sustainable bio-innovations that increase resource use efficiency, improve environmental outcomes in agrifood systems; and
ii. providing support to countries and regions and institutions in developing and implementing integrated, evidence-based bioeconomy strategies, policies and programmes.

In its work on bioeconomy, FAO recognises gender, youth, and inclusiveness as cross-cutting themes. Activities are scaled up through four accelerators: biological, digital and engineering solutions; bio-based innovations; disaggregated data to monitor new bio-based solutions; and policy, investment and partnership decisions in bioeconomy innovation.

FAO's initiatives in the bioeconomy contribute to the better environment pillar and support better production, better nutrition, and a better life, while leaving no one behind (Figure 6). FAO provides Members with policy advisory, capacity building and deployment of bio-innovations on the ground, building partnerships, and knowledge creation and advocacy.

FIGURE 6. PPA BE2 Key Work Areas



Source: Authors' own elaboration

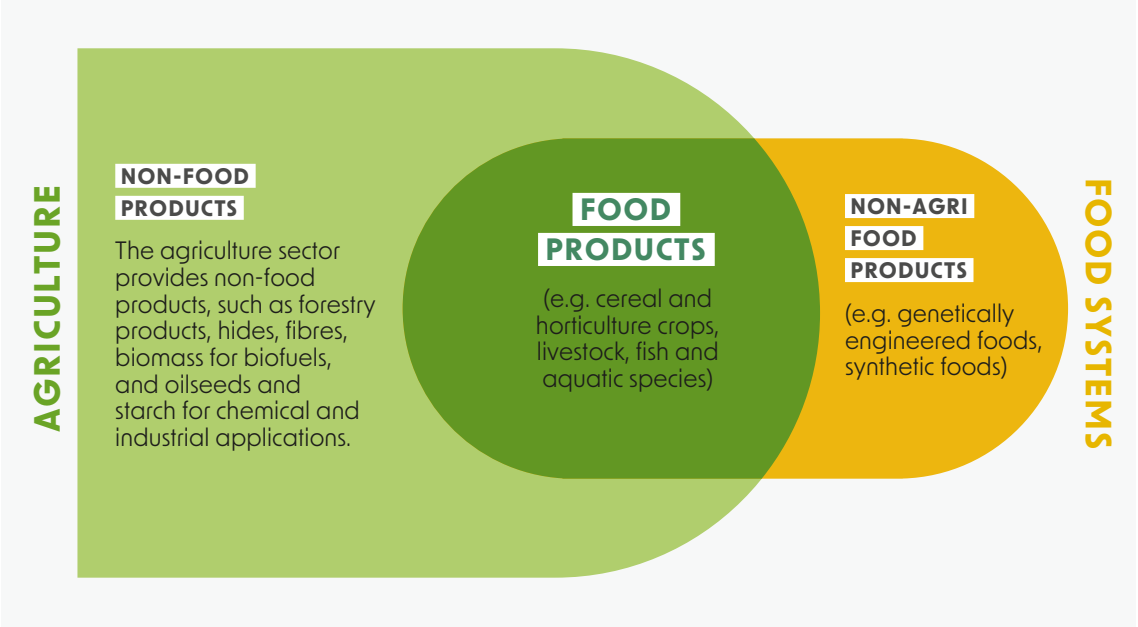
4.2 FAO WORK ON THE BIOECONOMY: AN INTEGRATED APPROACH FOR AGRIFOOD SYSTEMS TRANSFORMATION

The ability of agrifood systems[13] to provide food and raw biomaterials without depleting natural resources amid growing environmental pressures places them at the centre of bioeconomy development (Figure 7). Achieving this requires an integrated approach that balances the environmental, social, and economic dimensions of sustainability, fosters innovation, promotes the adoption of sustainable practices, and encourages stakeholder collaboration. It underscores the importance of supportive policy frameworks and investments to transform agrifood systems for a sustainable future.

The bioeconomy includes biomass production sectors (e.g. crop and livestock production, fisheries and aquaculture, and forestry), secondary processing sectors (e.g. agro- and bio-industries), and tertiary sectors (e.g. ecosystem services, waste management, and bio-based science, data, technology and innovation). A central component of bioeconomy is the use of biological resources and processes (e.g. microorganisms, bioprocesses, bioinformatics) across these sectors that lead to a fundamental shift in production activities and services.

13 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 fibres) that provide livelihoods to millions. They also encompass the activities, services, investments and decisions that play a part in sustainable consumption (Figure 7) (FAO, 2021c).

FIGURE 7. Agrifood systems definition



Source: Adapted from **FAO**. 2021. *Forty-second Session of the Conference. Agriculture Food Systems Transformation: From Strategy to Action.* C 2021/28. (Also available at: https://openknowledge.fao.org/server/api/core/bitstreams/78538a18-fd68-49d8-b7c0-e0ed03a80de8/content)

Both agrifood systems and the bioeconomy encompass food, non-food products (e.g. wood and non-wood forest products, biofuels, feed and fibres), and non-agrifood products (Figure 7). They also include the communities, labour, and all the other activities, investments and behaviours that play a part in the production, processing, distribution and marketing, consumption, and disposal of food and agricultural products (FAO, 2021c). At the core of FAO's work are the four dimensions of food security: food availability; access to food; food utilization (i.e. consumption and nutrition); and the stability of the other three dimensions over time, which is enabled by a system that remains stable in the event of climatic, economic, social or political disruptions. The bioeconomy and agrifood systems are intrinsically linked. Because the bioeconomy includes sectors like construction and health, it has a broader, more resource-oriented and cross-cutting scope than agrifood systems and its related industries, connecting agrifood systems with the broader economy as the biomass flows across sectors.

On the one hand, agrifood systems contribute to the bioeconomy by providing the biological resources that are essential to produce bio-based products, processes and services that can improve the sustainability of other economic sectors. This requires sustainably increasing the production of biomass, optimizing the utilisation of existing biomass, and tapping into underutilized and undervalued biomass sources (e.g. by-products and waste) (Meybeck *et al.*, 2024b). On the other hand, science, technology and innovation associated with bioeconomy can enhance the effectiveness, sustainability, inclusivity, and competitiveness of agrifood systems (FAO, 2022a). The transformative potential of bioeconomy was recognized in national Food Systems Transformation Pathways submitted to the 2021 Food Systems Summit. Most of the 127 Pathways that were submitted prioritized approaches (e.g. sustainable consumption and

production) related to bioeconomy. Brazil, Costa Rica, Finland, France, Germany, Latvia, Poland, Türkiye, and Uruguay explicitly mention bioeconomy in their Pathways. Rural development and entrepreneurship, bioinputs, indigenous knowledge systems, and access to markets are examples of the issues that were being addressed (FAO, 2024a).

One way the bioeconomy can transform agrifood systems is by increasing efficiency through circularity and the cascading use of biomass[14], which involves recycling and maximizing the utilization of biological resources throughout their lifecycle. This enhances sustainability by valorizing residues from crops, livestock, fisheries, aquaculture, and forestry, creating new market opportunities and fostering intersectoral cooperation. For instance, crop residues can replenish soil nutrients or be used for feed, energy, and other products. Integrated systems in both rural and urban areas can localize resources, promoting local biomass processing and reducing reliance on imports. The bioeconomy also catalyses equitable economic development and social progress within agrifood systems by accessing new resources and markets, increasing resilience, and generating new income streams and employment opportunities (Wessel and von Braun, 2017). It encourages diversified farming practices and connections with emerging sectors. By adding value to agricultural commodities and promoting local processing and manufacturing, the bioeconomy stimulates entrepreneurship and improves the quality of life, especially in rural areas where biomass is produced, and extends opportunities to urban settings for growing biomass for food and materials (Lokko *et al.*, 2018).

4.2.1. BIOECONOMY FOR A BETTER ENVIRONMENT

Through its work on the bioeconomy, FAO aims to achieve its overarching goal of a better environment by "protecting, restoring and promoting sustainable use of terrestrial and marine ecosystems (reduce, reuse, recycle, residual management) and combatting climate change" (FAO, 2021d). By fostering sustainable production practices, substituting fossil-based resources and chemicals with biological alternatives, and sequestering carbon into bio-based products, the bioeconomy provides many options for reducing the impacts on climate change of agrifood systems (Gomez San Juan, Harnett and Albinelli, 2022a). Bioeconomy policies, technologies and innovations can support the delivery of the FAO strategies on Climate Change (FAO, 2022b), Mainstreaming Biodiversity across Agricultural Sectors (FAO, 2020), Science and Innovation (FAO, 2022c), and Corporate Environmental Responsibility (FAO, 2021e).

FAO has developed the FAO Dashboard on bioeconomy which collects and provides information on national and regional bioeconomy strategies, strengthening the evidence base for decision-makers and helping them develop and implement comprehensive and effective bioeconomy strategies. The Dashboard indicates that all bioeconomy strategies strive to reach climate mitigation and adaptation objectives (FAO, 2024a). Examples include microbiome innovations that enhance soil carbon sequestration and soil health, and biofertilizers and biopesticides that offer more sustainable options for improved production than synthetic inputs. FAO has undertaken a systematic review of more than 2 000 scientific publications to understand the direct correlation between crop production, the soil microbiome, and the impacts of climate

14 Cascading use involves the reuse of residues and the recycling of materials across the value chain. In a cascading approach, the biomass is processed into a bioproduct that is used at least once more (single-stage use) or several more times (multi- stage use), either for materials or energy, before disposal (Gomez San Juan, Bogdanski and Dubois, 2019).

change. The review offers important insights as to how the climatic and environmental impacts of agrifood production systems could be reduced (Kendzior, Warren Raffa and Bogdanski, 2022a).

The development of the bioeconomy can also be an opportunity to reduce harmful subsidies that contribute to the unsustainable use of agrochemicals, the excessive use of antibiotics, the deforestation or drainage of lands for agricultural production, and the use of fossil fuels. FAO supports countries to identify sustainable alternatives to agrochemicals and provides technical assistance to Rotterdam Convention Parties on the use of hazardous pesticides, biological alternatives, and integrated pest management (Box 10). In Kenya and Uruguay, FAO works on reducing the use and prevalence of harmful agrochemicals by enabling farmers to access finance for the adoption of alternatives. In Liberia, FAO is strengthening soil analysis and information systems to improve sustainable soil management and support evidence-based decision making on soil preservation and sustainable land use (FAO, 2023c).

Bio-innovations that minimize emissions and foster circular systems can transform waste into valuable resources, (e.g. bio-based and biodegradable plastics, textiles and sustainable bioenergy) and add value to underutilized residues and by-products from crop, forest and aquatic systems. The first-ever FAO/GEF bioeconomy project, "Bananas in Pakistan's Bioeconomy: Transforming Waste into Textile", adds value to non-edible biomass from banana production by using it in the production of a sustainable, alternative textile fibre. This process keeps the biomass from being burned in the open or disposed of in landfills (FAO, 2023e).

By hosting the Global Bioenergy Partnership (GBEP), FAO supports countries in the sustainable development of bioenergy (FAO, 2024e). For example, in Viet Nam and Zambia, FAO has promoted the sustainable production of bioenergy from residues. In Paraguay, FAO projects promote sustainable management practices to produce ethanol and biodiesel (Pirelli, Rossi and Miller, 2018; Pirelli and Rossi, 2018; FAO, 2021f). A 2023 FAO report, *The role of wood residues in the transition to sustainable bioenergy*, provides an overview of the potential use of wood residues as feedstock for bioenergy production in the transition towards a sustainable and circular forest-based bioeconomy (Zuzhang and Walter, 2023).

Developing a sustainable bioeconomy can also contribute to the conservation and restoration of biodiversity and ecosystems, and support efforts to meet the Kunming-Montreal Global Biodiversity Framework (GBF) targets:

- bioremediation can help restore degraded areas (Target 2);
- biosciences can enhance the *in situ* and *ex situ* conservation of biodiversity (Target 4);
- bioproducts (biofertilizers, biopesticides, bio-based plastic, biofuels) can reduce pollution and pesticide risk (Target 7);
- the development of local value chains based on sustainable biological resources can empower local communities by creating opportunities to diversify incomes (Target 9);
- measures to ensure the equitable distribution of benefits strengthen access and benefit sharing mechanisms (Target 13) (Box 11); and
- circular bioprocesses foster sustainable consumption and reduce food waste (Target 16).

BOX 10. CASE STUDY **Bioinputs for crop, animal and aquaculture production**

The FAO Investment Centre analyses of the cost and benefits, the market potential, and the externalities connected with the adoption of agricultural bioinputs in Latin America (Bullor *et al.*, 2023). Case studies are identified to investigate opportunities for scaling up the production, commercialization and application of these bioinputs. For example, in the Plurinational State of Bolivia, a mix of microbial biofertilizers and biopesticides (e.g. *Bacillus amyloliquefaciens, Bacillus megaterium, Beauveria bassiana*) are applied to fruit trees (blueberries for export and apples and peaches for local markets). Each case study provides information on the impact of adopting bio input, the risk factors, the barriers and incentives (e.g. subsidies), and the hidden or avoided costs. FAO is also implementing several projects on bioinputs, for instance in Panama, where the Organization is supporting the production of biofertilizers from sargassum seaweed.

Bioinputs have significant applications beyond just plants and crops, extending their benefits to animal production as well. In the realm of animal husbandry, bioinputs include probiotics used in animal feed, which help improve digestion and overall health. Additionally, bio-based medicines are being developed as alternatives to conventional pharmaceuticals, aiming to enhance animal health and reduce the reliance on synthetic drugs. For instance, enhanced feed ingredients can ensure better nutrition, addressing antimicrobial resistance by promoting safer alternatives to antibiotics, and ensuring biosafety to prevent disease outbreaks.

Source: **Bullor, L., Braude, H., Monzón, J., Cotes Prado, A. M., Casavola, V., Carbajal Morón, N. and Risopoulos, J.** 2023. *Bioinsumos: Oportunidades de inversión en América Latina - Direcciones de inversión* No. 9. Roma, FAO. https://openknowledge.fao.org/handle/20.500.14283/cc9060es

The FAO Dashboard on bioeconomy provides information about the links between bioeconomy strategies and national biodiversity objectives. In this way, FAO's work on the bioeconomy contributes to PPA BE3: "Biodiversity and ecosystem services for food and agriculture".

Bioeconomy can also strengthen sustainable urban agrifood systems (PPA BL3) as a part of the FAO *Framework for the Urban Food Agenda*. The urban dimension of bioeconomy is expanding under the FAO flagship "Green Cities Initiative" (GCI). By 2030, the GCI aims to make a tangible impact on the health and well-being of people in 1000 cities, while actively addressing urbanization challenges by integrating urban and peri-urban forestry, agriculture and bioeconomy into the fabric of urban life. The first pilot has been implemented in Côte d'Ivoire, where a circular bioeconomy business model has been applied to transform waste into inputs for sustainable urban agriculture (Box 14) (FAO, 2023f).

BOX 11. CASE STUDY **Bioprospecting and access and benefit sharing**

The International Treaty on Plant Genetic Resources for Food and Agriculture, hosted by FAO, manages the Benefit-sharing Fund, which supports projects leveraging plant genetic resources to enhance food security, nutrition, rural livelihoods, and climate change adaptation. To date, it has funded 80 projects across four cycles, collaborating with over 500 organizations. The primary beneficiaries are farmers in low- and middle-income countries. Projects focus on three main areas:

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

4.2.2. BIOECONOMY FOR BETTER PRODUCTION

As outlined in Chapter 2, many countries see the bioeconomy as a driver for sustainably increasing productivity, diversifying local incomes, and increasing the resilience of agrifood systems. The application of expertise and technology can drive a transition to a sustainable bioeconomy that can increase value-addition and generate new products and businesses by improving how natural resources are used in production processes, for example through the optimization of available biomass use or the exploitation of underutilized bioresources. In this way, bioeconomy can contribute to achieving PPA BP1: "Innovation for sustainable agriculture production". The efficient use of biomass and underutilized residues, by-products, and waste can minimize trade-offs, especially those associated with the competition for food and feed.

The resilience and adaptive capacity of agrifood systems can be strengthened by developing new cropping systems that respond to varying conditions. Innovative breeding techniques can increase the adaptive capacity of plants and animals to a changing environment (e.g. improving the heat-resistance and drought-tolerance of crops), address biotic and abiotic stresses, enhance disease resistance, increase production yields, and reduce the need for external inputs (e.g. fertilizers, pesticides and water) (Zilberman *et al.*, 2013). Integrating technology and data-driven approaches in farming practices allows for more precise resource management and optimizes the use of water and nutrients (Trigo *et al*, 2023). Biological products and techniques, such as microbial-based soil amendments and biofertilizers, also improve the retention of nutrients and water in soils.

Biotechnology, within the broader context of science and innovation, has been recognized in the FAO Strategic Framework as one of the critical drivers for the sustainable transformation of agrifood systems. Digital and biotechnologies are used in several FAO projects. For example, in Turkmenistan, FAO is pioneering digital and precision agriculture approaches for sustainable pasture management. In Thailand, FAO is deploying biotechnology to combat shrimp diseases.

BOX 12. CASE STUDY

The Sterile Insect Technique boosts production and protects the environment

In Ecuador, fruit production, including non-traditional fruits such as dragon fruit (*pitahaya*), golden berry (*uvilla*) and tree tomato, is increasing. However, the presence of a complex population of fruit flies, in which the Mediterranean fruit fly is the predominant species, causes damage and restricts access of these high-value fruits to international markets. Countries that are free from fruit fly apply quarantine regulations to fruits grown in areas where fruit fly species are present. With assistance from FAO and IAEA, Ecuador has been able to implement a fruit fly control scheme based on integrated pest management (IPM). The scheme has led to the implementation of IPM over 10 700 hectares of commercial fruit production, which has significantly reduced fruit fly damage and increased yields. In 2018, the sterile insect technique (SIT) was introduced to Ecuador and integrated into the IPM approach specifically to eliminate the Mediterranean fruit fly. Three million sterile Mediterranean fruit flies were shipped each week from Guatemala and released over the targeted production areas within the total area under IPM practices. This approach has established areas of fruit fly low prevalence and reduced the risk of infestation. Fruit production and quality has increased and, the export markets to the United States of America have opened up to these non-traditional fruits (Manrique and Enkerlin, 2023).

Source: **Manrique, V., Enkerlin, W.** 2023. The use of the sterile insect technique as part of an integrated pest management approach to control fruit flies in Ecuador. In: Ruane, J., Mba, C., Boettcher, P., Koskela, J., Mair, G. and Ramasamy, S., eds. 2023. *Case studies of the use of agricultural biotechnologies to meet the needs of smallholders in developing countries*. Rome, FAO. https://doi.org/10.4060/cc8940e

Innovative pest control schemes using nuclear biotechnologies, such as the sterile insect technique (SIT), can have significant benefits for farmers and the environment and reduce or eliminate the use of pesticides. SIT involves mass rearing and sterilization of male insects, which are subsequently released over areas where the same insect species is a pest. Pest reproduction is then inhibited as the females fail to produce offspring. As sterile males are continuously released, the pest population is gradually reduced each generation until it can be easily eradicated from the area (Box 12).

Space may be one of the next frontiers in the development of a sustainable bioeconomy. FAO in collaboration with the IAEA implements a project studying the effects of cosmic radiation on the natural genetic adaptation of crop seeds (FAO, 2023g). Other projects include generating satellite images of crop conditions (FAO, 2023h; WEF, 2021) and using cosmic rays to measure soil moisture level (Beninger and Jawerth, 2018).

The bioeconomy can also contribute to better land use, and the restoration and remediation of polluted lands. If the infrastructure exists, non-food production can be used to drive this process. An example of this is the "Promoting Sustainable Use of Underutilized Lands for Bioenergy Production through a web-based platform for Europe" (BIOPLAT-EU) project. For this project, FAO has mapped marginal, underutilized, and contaminated (MUC) lands for non-food biomass production in the European Union and Ukraine. The project developed an

open-access user-friendly web geographic information systems (web-GIS) platform to assess the environmental, social, technical and economic sustainability of bioenergy value chains based on the cultivation in MUC land (Khawaja *et al.*, 2021). Through the iterative use of this web-GIS tool, which was developed using the Global Bioenergy Partnership (GBEP) methodology, various scenarios were simulated and compared, which served to optimize the interlinkages among the various domains of the land–water–energy nexus (Pulighe and Pirelli, 2023). The MUC land identified and mapped was used for the cultivation of non-food crops for bioenergy and the production of other bio-based products.

By adopting sustainable agricultural practices like crop rotation, intercropping, and cover crops, it is possible to grow food and non-food products together. This approach, used in systems like agroforestry and integrated food-energy production, allows to use the same land for multiple purposes. For example, to grow crops that provide both food and materials, or use biomass in various ways (Gomez San Juan, Bogdanski and Dubois, 2019). In Azerbaijan, FAO is supporting small-scale farmers to adopt good agricultural practices and improve the efficiency of hazelnut production, using hazelnut residues to produce bioenergy (FAO, 2022d). This work illustrates how bioeconomy can be used to support small-scale producers and contribute to achieving the objectives of PPA BP4: "Small-scale producers" equitable access to resources.

Sustainable bioeconomy development also extends to aquatic food systems. The blue bioeconomy, which is a significant component of the broader bioeconomy, encompasses activities related to oceans, seas, and freshwater ecosystems. It involves the sustainable use of marine resources and the conservation and protection of marine ecosystems (World Bank, 2017). Sustainable bioeconomy development aligns with PPA BP2: "Blue transformation". This has been recognized by the thirty-sixth Session of the FAO Committee on Fisheries (COFI), which "called on FAO to integrate sustainable aquatic products into the broader implementation of bioeconomy programmes especially those related to SSF, Indigenous Peoples and local communities" (FAO, 2024f). The blue bioeconomy is a high priority for sustainable development in SIDS.

As part of the Blue Growth Initiative, in Kenya FAO works on blue fashion, using aquatic raw materials and by-products to develop bio-alternatives for the fashion industry (FAO, 2018b). In Asia and the Pacific, FAO has supported countries in adopting and scaling up innovations and good practices for the sustainable intensification and expansion of aquaculture. In this context, algae play an important role, as they serve as nutritious food and feed for aquaculture; a source of material for biofuels and bioremediation, and a feedstock to generate products of added value (Box 13). In Panama, FAO is supporting farmers to use seaweed for a range of products (FAO, 2022e). In Barbados, FAO has successfully introduced the production of fish silage for animal feed and fertilizer by using by-products of fish processing and molasses production, which has provided additional livelihood opportunities to women and youth (FAO, 2023i). In Colombia, Sri Lanka, and the United Republic of Tanzania, FAO has been contributing to the sustainable use of fisheries and aquaculture products and the development of the bioeconomy through the application of a multi-dimensional solutions approach to reducing aquatic food loss and waste (Calderón Gómez, n.d.; FAO, 2022f; FAO, 2024g). In this approach, strategies emphasize the circular economy and related technologies, the adaptation of infrastructure, the generation of skills and capacities, and strategic links with markets and policies.

BOX 13. CASE STUDY — Social, economic and environmental contribution of seaweed

Aquaculture is the main source of global seaweed production. In 2022, 36.5 million tonnes of seaweed were harvested, which accounted for nearly 30 percent of the total global aquaculture production and had a value of nearly USD 17 billion at first sale (FAO, 2024a).

Most seaweed species are edible, and human consumption of seaweeds dates back centuries. Edible seaweed remains an important part of the diet in many coastal communities. They are generally rich in dietary fibre, micronutrients, bioactive compounds, and a good source of essential fatty acid, such as the long-chain polyunsaturated omega-3 fatty acids. Seaweed is also processed into food and feed additives and supplements. Seaweed cultivation is labour intensive, requires little capital investment and uses simple technologies. For these reasons, it provides an accessible opportunity to earn a livelihood for many resource-poor households or vulnerable individuals. It also makes a significant contribution to community cohesion and women's empowerment. Seaweed and microalgae also provide important environmental benefits and ecosystem services. Seaweed cultivation does not use land, freshwater or feed. By extracting nutrients (nitrogen and phosphorus) from surrounding waters and absorbing carbon dioxide through photosynthesis, seaweed and microalgae can mitigate eutrophication, treat wastewater, reduce ocean acidification, and capture carbon. Seaweed and microalgae cultivation can contribute to global sustainable developmental objectives related to food security and nutrition, economic growth and decent employment and social well-being (FAO, 2023a).

FAO has prepared and disseminated a number of knowledge products and implemented various projects that have been either focused on seaweed or that included seaweed development as a component. This work has included (i) developing practical manuals on seaweed cultivation; (ii) establishing technical platforms to facilitate capacity building, the transfer of technologies and the sharing of knowledge on farming systems, genetic improvement, disease control and other critical areas (FAO, 2024b); (iii) supporting market development for seaweeds as food; and (iv) facilitating collaboration and cooperation among FAO Members in strengthening governance for the sustainable development of the algae sector (FAO, 2023b). FAO has published a background document, Report *of the expert meeting on food safety for seaweed – Current status and future perspectives*, that identifies potential food safety hazards that could be linked to the consumption of seaweeds and lays a foundation for further work in this area (FAO and WHO, 2022). As part of its work on aquatic genetic resources, FAO is also developing an information system on algae and different types of farmed aquatic plant species that can help address the information gaps related to the genetic basis of seaweed cultivation (FAO, 2024c).

Sources: See References Box 13

The One Health approach, which falls under PPA BP3: "One Health", links the health of people, animals, and ecosystems. Bio-based options have promising potential for reducing chemical usage in agriculture, mitigating environmental contamination and lowering risks to human and animal health. Advancements and innovations in microbiome science can provide valuable insights into the intricate relationships between humans, other animals, and their surrounding ecosystems (FAO, 2023j). The application of prebiotics, probiotics, synbiotics, and postbiotics has demonstrated advantages A more comprehensive understanding of these relationships and the interdependence of all living beings can lead to a more holistic approach to health management and disease prevention. In Europe and Central Asia, FAO is strengthening technical capacities and creating an enabling environment to reduce the progression of antimicrobial resistance in food and agriculture (FAO, 2024h).

Because of its reliance on biological resources and processes to produce goods, services, and energy in a sustainable manner, bioeconomy is intrinsically connected to the water–energy–food (WEF) nexus. The WEF nexus approach emphasizes the critical interdependencies and feedback loops between water, energy, and food systems, which are essential for ensuring food security, reducing poverty, improving human health, and protecting the environment (FAO, 2014). Bioeconomy supports the water–energy–food nexus by providing bio-based materials and bioenergy resources, which can lead to more sustainable agricultural practices and reduce the pressure on water and energy resources. For example, using wastewater from food production for irrigation can decrease the demand for freshwater resources, and producing biogas from organic waste can provide an alternative energy source while optimizing the use of water and energy in food production. Finally, bioeconomy intersects with the water–energy–food nexus by offering integrated options such as e.g. co-locating bioenergy facilities with wastewater treatment plants allows for organic waste to be used to both generate renewable energy and improve water quality.

4.2.3. BIOECONOMY FOR BETTER NUTRITION

The sustainable use and management of agricultural biomass should first serve to meet the world's food and nutritional needs before supplying raw materials for energy or industrial purposes. The ultimate objective of transforming agrifood systems through the sustainable development of the bioeconomy is to guarantee food security and food safety, improve nutrition, and increase everyone's access to healthy diets. By stimulating advancements in biotechnology, bioeconomy can support the cultivation of nutrient-rich crops that address common micronutrient deficiencies in staple foods. The sustainable development of the bioeconomy can contribute to achieving PPA BN1: "Healthy diets for all". This includes the valorization of neglected and underutilized crop specifies, and the breeding of iron- and vitamin-fortified legumes and grains. In Ethiopia, through the "Food and Nutrition Security Impact, Resilience, Sustainability, and Transformation" (FIRST) project, FAO has supported initiatives that encourage the market-oriented cultivation of nutrient-rich crops, including biofortified crops.

The *FAO Roadmap Achieving SDG 2 without Breaching the 1.5 °C Threshold*, launched in 2023 during the 28th Conference of the Parties (COP) to the UNFCCC, presents bioeconomy as an opportunity to achieve SDG target 12.3 to halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains by 2030 (FAO,

2023k). Indeed, bioeconomy can reduce food loss and waste at all stages of the food chain, making it important for advancing PPA BN4: "Reducing food loss and waste". By encouraging sustainable farming methods (e.g. precision farming, integrated pest management, and soil conservation), bioeconomy reduces losses before harvest and guarantee more effective use of agricultural resources. Improvements in preservation methods made possible by biotechnology advancements can prolong the shelf life of perishable goods and contribute to ensuring "Safe food for everyone" (PPA BN3). There are opportunities to give value to food that is lost or wasted within circular bioeconomy approaches. This organic matter contains nutrients that can be recovered to support nutrition and food security, and eventually be recycled through various processes (e.g. composting, anaerobic digestion, or bioconversion) (Box 14). This is particularly evident in production systems that process fish into fillets, where between 30 and 70 percent of the fish body is removed as a by-product. Because these by-products are usually not considered as food, they are also not counted as food loss or waste if not utilized. From a nutritional point of view, these by-products (e.g. heads, backbones and trimmings) are of higher value than the main product, particularly when it comes to micronutrients. Through simple processing, these by-products can be converted into fish powder. FAO has been testing this option in terms of acceptability and food safety and has had promising results. Dried fish powder is high in nutrients (e.g. calcium, iron and zinc) and, depending on which part of the fish is used, it can also be a rich source of vitamin B12 and vitamin A. The product is nutrient dense, can easily be transported and stored, and improves the taste of the meal.

Disruptions to the gut microbiome have been linked to undernutrition, obesity, other forms of malnutrition and diet-related non-communicable diseases. Microbiome science offers a path to more sustainable, personalized, and effective nutritional options to alleviate the global burden of malnutrition (Callens *et al.*, 2022). FAO is building a body of knowledge on the role of microbiomes in agrifood systems. A 2022 FAO publication, *A Review of the impacts of crop production on the soil microbiome*, explores the role of the microbiome in connecting humans, animals, plants and their surrounding ecosystems.

BOX 14. CASE STUDY **Upcycling unavoidable urban organic waste**

FAO is looking into new food and feed sources and their role in providing access to balanced and healthy diets. The IPCC WGII Report notes that microbial proteins, plant-based alternatives, and insect-based proteins can play a role in diversifying diets and addressing global malnutrition. In particular, an increased consumption of alternatives to animal source foods can reduce greenhouse gas emissions, alleviate pressure on natural resources, preserve biodiversity and curb malnutrition in low- and middle-income countries (IPCC, 2022). FAO is currently exploring the role of alternatives to animal source foods to address dietary challenges and has established an internal cross-cutting task force to expand knowledge in this area. New and traditional bioeconomy processes (e.g. biomass fermentation and precision fermentation techniques) can increase availability of protein-rich foods and introduce more efficient and sustainable production methods. FAO has been reviewing the latest microbiome research to deepen the understanding of nutrition, and how diets and food products, through the environment in our gut, affect the resilience of the human body to withstand stress and disease, particularly non-communicable diseases related to food (FAO, 2019).

In relation to new feed alternatives, FAO is implementing a project in Abidjan where black soldier fly is reared on urban waste. The dried larvae are then used for chicken feed and the only by-product of the process, the larvae frass (feces), is used as organic fertilizer. In 2023, local partners (the *Institute d'Economie Circulair*e of Abidjan [IECA] and the start-up Bioani) have built a 1000 square meters black soldier fly farm in the public nursery of Abobo, Abidjan. Around 1 000 kg of organic waste is collected daily from local markets and brought to the farm, where it is bio-converted by black soldier fly larvae into proteins for poultry feed. The by-product of the process, the frass, is used to produce organic fertilizer. Each day, around 120 kg of feed is produced from the dried larvae and 200 kg of organic fertilizer is produced from the frass, which is sold to urban and peri-urban farmers at a cheaper price than conventional products. The farm employs young women and men and serves as a Farmer Field School (FAO, 2024). This project includes peer-to-peer learning and collaboration with other countries, to enhance best practice knowledge management and uptake. In the Caribbean, FAO promotes insect production as a high-quality protein alternative for poultry and aquaculture feed. It is a way of creating new and diversified livelihood opportunities and to increase resilience, sustainability and food security (FAO, 2022).

Sources: See References Box 14

4.2.4. BIOECONOMY FOR A BETTER LIFE

FAO work on the bioeconomy contributes to creating inclusive agrifood systems by addressing inequalities and by fostering resilience, income diversification, green job creation and rural transformation. FAO facilitates capacity development and technology transfer for farmers, rural communities, women, youth, and other stakeholders. For example, in Pakistan, FAO promotes the in-situ conservation and sustainable use of medicinal plants and other non-timber

forest products (NTFPs) by providing capacity building activities that help local communities in valorizing them (FAO, 2024i). In Cameroon, Papua New Guinea, Paraguay, the Philippines, and Viet Nam, FAO enhances the role of forests, trees, and non-wood forest products (NWFPs) in sustainable agrifood systems. This project aims to build capacity, promote inclusive policies, and mobilize resources to optimize the potential of neglected forest resources like wild plants, fungi, and insects, addressing nutrition, poverty, biodiversity, and climate priorities (FAO, 2024j).

In rural and urban areas, the bioeconomy can serve as a catalyst for positive change, enabling communities to benefit from new activities and businesses based on the production and transformation of biological resources (OECD, 2021). This can diversify income sources, enhance resilience, reduce unemployment and support formal economies. In sustainable bioeconomy development, emphasis is placed on decentralized biomass processing, which can serve to revitalize rural economies, reduce outmigration and create employment alternative (von Braun, 2014). In Peru, FAO is improving the well-being of forest communities and strengthening the resilience in Amazonian forests by enhancing the value of biodiversity for food security and businesses, while conserving healthy and functional forests and wetlands. This is achieved through promoting collaborative governance, strengthening landscape connectivity, and encouraging sustainable production practices (GEF, 2024). FAO also engages in dialogue with Indigenous Peoples and local communities in the development of the bioeconomy in the Amazon. The Regional Technical Dialogue on Amazonian Bioeconomy and Inclusive Rural Transformation, organized by FAO and the Amazon Cooperation Treaty Organization (ACTO), identified opportunities, emblematic cases, and recurring challenges for the adoption of an Amazonian bioeconomy model that meets the need for an inclusive rural transformation where no one is left behind (FAO, 2024k). In several rural communities in Colombia, FAO is establishing an inclusive model of territorial food supply in collaboration with small and medium-sized producers. The project involves implementing circularity principles to develop agro-industries that utilize by-products from various productive activities, including fish and poultry farming, banana, coffee, biofertilizers and dairy (FAO, 2023l). In this way, bioeconomy contributes to PPA BL2: "Inclusive rural transformation". An example presented in Box 15 highlighting how FAO's Blue Fishing Ports Initiative contributes to supports goals of the PPA BP2: "Blue Transformation".

BOX 15. CASE STUDY

Coastal blue bioeconomy – the importance of fishing ports

The FAO Blue Fishing Ports Initiative (BPI) strengthens the role of ports as drivers of sustainable development in coastal cities and communities. It improves data collection and enforcement, upgrades infrastructure and services, encourages innovation and entrepreneurship, preserves natural capital and strengthens fishing value chain. All these actions contribute to addressing national and global challenges related to sustainable development in marine and coastal areas. Currently, more than 20 countries from Africa, Asia and Latin America and the Caribbean are part of the BPI (FAO, 2024a).

Continues on the next page

The BPI, which has established a strategic model to transform ports into hubs of sustainable development, focuses on inclusivity and works to involve all local communities, global partners, academia, private enterprises, governments and other stakeholders. The 2023 publication, *Roadmap to a blue port* (Molares, Estors Carballo and López de Aragón, 2023) outlines methodological steps that fishing ports can follow to enhance managerial capacities. It includes a review of good practices that can enable fishing ports to contribute to bioeconomy development, promote circular bioeconomy approaches, foster innovation and strengthen entrepreneurship.

There are several examples that can illustrate the role of fishing ports in the urban blue bioeconomy. The Indonesian port of Bitung has implemented a ban on environmentally harmful fishing gear and coupled this with stringent entry and exit permit enforcement to ensure compliance. In collaboration with local waste management organizations, the port has established a comprehensive waste management system to prevent the accumulation of waste through an on-site waste bank that transforms waste into valuable resources (FAO, 2024b).

A FAO project in the Marshall Islands supports the maintenance and repair of refrigerated containers to build a hub for tuna containerization in the Pacific (FAO, 2024c; FAO, 2022). In Dominica, the pioneering Women Sea Moss Farmers project has collaborated with the private sector to diversify and build the blue economy and aquaculture sector by developing the sea moss value chain, which is a high priority for the country (FAO, 2024d). FAO is working to make Zambia's small pelagic fish value chain stronger and more sustainable by empowering women in fishing communities, improving access to markets and promoting alternative livelihoods to diversify incomes (FAO, 2024e).

FAO is implementing a series of projects on the development of aquatic food value chains in different regions of the world.

- "FISH4ACP", which is a large-scale initiative of the Organization of African, Caribbean and Pacific States (OACPS), contributes to food and nutrition security, economic prosperity and job creation by ensuring the economic, social and environmental sustainability of fisheries and aquaculture value chains. FISH4ACP works with twelve value chains in twelve ACP countries. It pays special attention to small and medium-sized businesses because of their potential to stimulate inclusive growth and bolster food security, particularly for women and young people (FAO, 2024f).
- "Sustainable Fish Value Chains for Small Island Developing States" (SVC4SIDS) has focused on developing sustainable fishery value chains in Cabo Verde, Kiribati, and Barbados (over the period 2020-2021). In these target countries, the project works closely with stakeholders to implement research and development activities (FAO, 2024g).
- "Sustainable Fisheries and Aquaculture Value Chains for the Mediterranean" (SVC4MED) is a FAO research and development project that analyses the value chains of farmed rainbow trout and wild-caught shrimp in Albania, Italy, Lebanon, Tunisia and Türkiye, and formulates strategies to increase social benefits and safeguard natural resources (FAO, 2024h).

Sources: See References Box 15

Sustainable forest management practices, ecotourism, and production of non-timber forest products can provide alternative sources of income that can help communities adapt to changing environmental conditions and economic challenges. To enhance sustainability and increase the productivity of value chains for wood and non-wood forest products from natural and planted forests, FAO supports its Members with technical expertise to strengthen policies, set up inclusive financial mechanisms, and establish transparent legal and institutional arrangements. FAO also assists many countries in integrating sustainability into forest product value chains through the revision of laws and guidelines, national standards, procurement policies, trade regulations and assurance systems for legal production. FAO has organized stakeholder exchanges and policy dialogues to address the opportunities and challenges associated with sustainable production, the use of forest products, and livelihood improvements. These efforts aim to accelerate the adoption of forest-based innovations, develop sustainable forest-based value chains, and foster public-private partnerships. FAO has also carried out evidence-based assessments to guide countries, regions, and institutions on integrating forests and forestry into a sustainable bioeconomy and promoting innovations for resource efficiency and value addition in forest products.

Women play a crucial role in the bioeconomy as they are often the custodians of natural resources and key participants in activities that use biomass. Bioeconomy initiatives can create opportunities for rural women to actively participate in decision-making processes and gain economic independence. FAO is working to ensure that the transformations brought about by the development of the bioeconomy do not lead to skewed growth that make existing social and gender disparities worse. This is in line with the FAO Gender Equality Policy (2020-2030) and PPA BL1: "Gender equality and rural women's empowerment". In Jordan, FAO is strengthening the resilience of rural women by supporting them in adding value to forest products and addressing the challenges associated with limited forest coverage. FAO has also supported Namibia and Uruguay in developing gender-sensitive national bioeconomy strategies (FAO, 2022g). As a result of this work, Martha Negumbo of the Eudafano Women's Cooperative in Namibia, was recognized in 2022 as a FAO Food Hero on World Food Day (FAO, 2022h). In 2022, during the run-up to COP27 to the UNFCCC, FAO conducted a capacity-building workshop on bioeconomy for a delegation of women climate negotiators from SIDS, enabling them to advocate more effectively for the integration of bioeconomy into the climate agenda (FAO, 2022i).

Recognizing that young people are already at the frontline in building more sustainable agrifood systems, FAO has mainstreamed youth in its work on the bioeconomy as a cross-cutting theme, which is in line with the FAO Rural Youth Action Plan (FAO, 2022j). By promoting inclusive growth, sustainability, and innovation, young people are instrumental in developing the bioeconomy. Through their engagement, research, entrepreneurship, and educational activities, young people can contribute to the adoption of sustainable practices, technologies, and policies that support social justice, economic growth, and improved environmental stewardship. Their proactive involvement and leadership are crucial to achieving the bioeconomy's full potential and tackling global issues in an all-encompassing and inclusive way. A 2023 FAO report, *Opportunities for youth in the bioeconomy*, provides a comprehensive analysis of key challenges and barriers to achieving greater youth inclusion in the bioeconomy. In Uzbekistan, FAO promotes integrated green and innovative communities by empowering rural youth and women, increasing their employment opportunities and building their adaptative capacities to deal with the consequences of the environmental crisis around the Aral Sea (UN, 2023).

Chapter 5. Gaps and opportunities

By integrating insights from the analysis of the global bioeconomy landscape (Chapters 2 and 3) and FAO's work on the bioeconomy (Chapter 4), key challenges and opportunities have emerged across the four main work areas under PPA BE2: policy support; capacity building and country support; partnership building; and knowledge generation, advocacy, and demand-side measures. The identified gaps and opportunities may guide FAO and its Members in advancing the bioeconomy agenda and contribute to the transformation of agrifood systems at global, regional, national, and sub-national levels.

Bioeconomy is an integrative concept that encompasses various economic sectors, notably the food and agriculture sectors. It provides a flexible framework adaptable to different national contexts and capacities, promoting the sustainable and innovative use of biological resources across industries. FAO has identified fifteen common sustainability objectives in national and regional bioeconomy strategies from safeguarding food security, replacing fossil-fuel-based products with sustainable bioproducts, encouraging efficient use of biological resources while protecting biodiversity, water, soil, and addressing climate action to creating jobs and revitalizing rural, peri-urban, coastal, and other areas and establishing fair and equitable value chains (Gomez San Juan and Bogdanski, 2021). Countries and regions face unique challenges requiring tailored solutions, but all bioeconomy strategies emphasize transitioning from fossil-based to renewable biological resources. This transition places agrifood systems at the core of the bioeconomy, as they produce renewable biological resources like food and non-food crops, forest and fisheries products, industrial side streams, by-products, organic waste, and others. Food security is a primary objective for half of the existing dedicated national bioeconomy strategies and regional strategies and is seen as an important element in the rest.

POLICY SUPPORT

The absence of a multilaterally agreed framework and guiding principles for "bioeconomy" has led to diverse, localized interpretations and strategies. While this diversity offers numerous opportunities, the resulting fragmentation hinders the coherence and effectiveness of global bioeconomy initiatives, which may cause misalignments in policy, research, and development efforts across borders.

1. Bioeconomy policies, strategies, and plans need to prioritize food security and nutrition for all, particularly vulnerable populations, and mainstream the transformation of agrifood system so that they become more efficient, equitable, resilient, and sustainable.
2. A multilaterally agreed bioeconomy framework, sustainability criteria and indicators are critical to the successful implementation of the bioeconomy approach, ensuring they reflect national circumstances and capabilities, are supported by empirical data and aligned with the SDGs.

Policy fragmentation and lack of policy coherence leads to conflicting priorities, duplicative efforts, and resource inefficiencies, impeding the development of a unified framework for bioeconomy advancement.

3. By establishing intersectoral governance mechanisms for bioeconomy, countries and regions should aim for increased policy coherence with relevant sustainable development frameworks. Leveraging the FAO Bioeconomy Toolbox and the FAO Dashboard on bioeconomy, among other resources, could assist countries in designing sustainable bioeconomy strategies and facilitate the exchange of good practices.

A whole-of-society approach is essential for a successful transition to a sustainable bioeconomy (e.g. ILO, 2023; Dietershagen and Bammann, 2023; OECD, 2020). Evidence shows that including vulnerable groups, Indigenous Peoples, youth, and women in bioeconomy initiatives leads to success. Disadvantaged groups deserve legal recognition and meaningful participation in policy and investment interventions. Women, who represented 37.8 percent of agricultural workers in 2021, face greater food insecurity and gender inequalities (FAO, 2023m). Bioeconomy initiatives can empower rural women economically and recognize their traditional knowledge. While young people and civil society organizations are starting to be included in global processes, they are often excluded from decision-making (Dietershagen and Bammann, 2023; European Union, 2024). Empowering youth to contribute to sustainable bioeconomy development is crucial for achieving its full potential and addressing global challenges inclusively.

Bioeconomy policies, strategies, plans, and practices often overlook the socio-economic, environmental, and governance **needs of less represented and vulnerable stakeholder groups**, such as women, youth, and Indigenous Peoples.

4. The principles of a just transition should be recognized and integrated into bioeconomy policies, strategies, and plans to ensure that no one is left behind, including small-scale agricultural producers, Indigenous Peoples, women, youth, and other vulnerable groups. Greater investments in education, training, and empowerment of youth, women, and vulnerable groups should aim at providing them with equal opportunities to participate in the bioeconomy.

If social sustainability is not properly addressed, the development of the bioeconomy risks exacerbating inequalities related to access to natural resources, exposure to environmental degradation, the distribution of knowledge, and rights to land and other resources. These inequalities are often most acute in rural communities. It is imperative that countries ensure that the shift to a sustainable bioeconomy contributes to rural development and poverty alleviation. By creating local value chains for bio-based products that can valorize waste, residues, and by-products available in rural areas, and through local processing activities and value addition, rural communities can capture more of the economic benefits generated by the bioeconomy. Ensuring that biomass processing occurs in rural areas will create employment opportunities in these communities and facilitate the creation of shorter value chains that reduce transportation costs and environmental impacts, including greenhouse gas emissions.

5. Increased resources are required to foster inclusive and equitable bioeconomy development in rural and urban areas promoting local bio-based value chains that valorize waste, residues, and by-products, while encouraging decentralized biomass processing. Boost rural and urban entrepreneurship, innovation, and job creation through policy incentives, technical assistance, training, and investment. These efforts could be further integrated into FAO's flagship initiatives, including the Green Cities Initiative, One Country One Priority Product, and the Hand-in-Hand Initiative.

CAPACITY BUILDING AND COUNTRY SUPPORT

The increased use of biomass for bio-based products could lead to changes in land use, the over-exploitation of natural resources, and increased competition for these resources, which **could exacerbate food insecurity and socio-economic inequalities**. This situation could be further worsened by the impacts of climate change.

6. 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.

Science, technology, and innovation are crucial for transitioning to a sustainable bioeconomy. However, high investment costs and limited access to technologies in low- and middle-income countries pose significant challenges. Overcoming cost hurdles and resistance from stakeholders benefiting from existing supply chains is essential. Future global challenges will increase the demand for specialized biological sciences, biotechnologies, and bio-innovations. Mechanisms supporting research, development, and the introduction of new practices and technologies are vital for bioeconomy development but often overlooked in agrifood and other bio-based sectors. Insufficient capacity building is a primary challenge for the safe application of modern biotechnologies in low- and middle-income countries (FAO, 2009).

7. Increased investments in bioeconomy science, technology, and innovation are crucial for supporting the transformation of agrifood systems, including crop and livestock production, fisheries and aquaculture, and forestry in low- and middle-income countries, utilizing funds like the Adaptation Fund, GEF, and GCF. Some key priority areas include enhancing south-south and triangular cooperation for technology transfer, promoting circular business models with demand-side measures, expanding from agricultural biotechnologies to new bio-based products, regenerating degraded areas through bioremediation and microbiome innovations, and applying behavioural science to encourage sustainable consumption of bioeconomy products.

PARTNERSHIP BUILDING

To realize the potential benefits of bioeconomy innovations and build holistic frameworks for action, FAO should increase its work on partnerships at all levels—global, regional, national, local, urban, and rural. This will ensure a comprehensive and inclusive approach to sustainable bioeconomy development.

8. The coordinated and synergistic actions needed to advance sustainable bioeconomy development would be bolstered by the establishment of a global multi-stakeholder platform or partnership with the participation of United Nations organizations. FAO could become a global convener of such a mechanism. It would help strengthen the role of food security and nutrition and agrifood systems transformation as key pillars of sustainable bioeconomy development. The global platform or partnership should serve as a catalyst for developing policies, strategies, and plans; building capacities; exchanging knowledge; and creating incentives for bioeconomy development at all levels.

KNOWLEDGE GENERATION, ADVOCACY, AND DEMAND-SIDE MEASURES

Bioeconomy has the potential to transform agrifood systems, making them more efficient, inclusive, resilient, and sustainable. However, it is essential to assess sustainability based on evidence-based principles, criteria, and indicators to ensure that agrifood systems can meet the growing demand for biological resources without compromising social, economic, and environmental dimensions of sustainable development. These principles and criteria should be defined by both specific national circumstances and capabilities and a shared global vision for the bioeconomy. The development and adoption of high-level principles for the bioeconomy proposed by the G20 Initiative on Bioeconomy (GIB) is a significant step towards designing the bioeconomy governance landscape. Good bioeconomy practices that have already been applied and tested can enrich international dialogue and promote knowledge sharing. In addition to reaching a consensus on principles, it is crucial to agree on the methodological approach to assessing and monitoring the sustainability of bioeconomy practices using SMART indicators.

Measuring and monitoring the sustainability of the bioeconomy is hampered by data quality issues and gaps, particularly concerning biomass and biowaste. The lack of agreed-upon international tools or indicators further complicates comparative analysis and the assessment of trade-offs.

9. Globally harmonized efforts are essential to support bioeconomy data collection and analysis, focusing on biomass availability, potential applications, and scenario modelling for policy development among others. Open access to bioeconomy data should be promoted where feasible. Integrating bioeconomy indicators into existing sustainable development and environmental reporting frameworks will streamline efforts and enhance policy coherence. Establishing common criteria and practical indicators for sustainable bioeconomy, aligned with the FAO Aspirational Principles and Criteria for a Sustainable Bioeconomy and other relevant standards, could increase transparency and accountability, thereby informing investments and fund allocation in the bioeconomy sector.

Consumer acceptance and demand for bio-based products are crucial for the development of a sustainable bioeconomy. Public opinion about biomass and innovative biological applications can be ambiguous. Willingness to pay price premiums for sustainable products varies, especially when unsustainable alternatives are subsidized. Bio-based products are often more expensive than fossil-based alternatives due to higher costs associated with biomass transport, delivery, and storage. Some studies indicate an increasing willingness among consumers to pay more

for certified bio-based products. Furthermore, consumer behaviour regarding sustainability, nutrition, and food safety is shaping the future of agrifood systems and the bioeconomy (FAO and WHO, 2019). Therefore, consumers need to understand that bio-based products have economic, social, and ethical value (Gomez San Juan, Bogdanski and Dubois, 2019).

10. To address the demand side of bioeconomy development, targeted support is required in several key areas. This includes enhancing consumer education on the benefits and value of bio-based products and promoting transparent labelling and certification to build consumer trust. Advocacy for policy changes to reduce subsidies for unsustainable alternatives is crucial, as is supporting research on consumer behaviour to inform marketing and product development. Efforts should focus on fostering innovation to lower costs associated with bio-based products and encouraging sustainable consumption patterns through guidelines and tools. Additionally, facilitating stakeholder collaboration to share good practices and align efforts is essential.

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Appendix 1. Bioeconomy lexicon

To understand and navigate the dynamic and evolving landscape of bioeconomy, it is crucial to be familiar with bioeconomy terminology. Many new terms or phrases, inspired by biological systems, have emerged within the bioeconomy. This bioeconomy lexicon is exclusively informative, and collects definitions of bio-prefixed words based on the glossary collected by FAO bioeconomy publications, FAO Terminology portal, the International Resource Panel of the United Nations Environment Programme, the European Commission Knowledge Center for Bioeconomy Glossary, the FAO Glossary of Biotechnology and Genetic Engineering, and the National Institute of Standards and Technology (NIST) lexicon.

Access and benefit sharing (ABS) – Arrangements that determine how genetic resources may be accessed and how users and providers reach agreements on the fair and equitable sharing of the benefits that might result from their use (CBD, 2011).

Bio-based carbon, biogenic carbon – Carbon derived from biomass (EC, 2024).

Bio-based industries – The application of biotechnology in production systems to make bio-based products or generate bioenergy from biofuels. In this report, the terms "bio-based industries" and "bio-industries" have been used interchangeably (Gomez San Juan, Bogdanski and Dubois, 2019).

Bio-based materials – The intermediate products that are used to make bioproducts. Traditional bio-based materials include wood for the production of furniture and construction materials, and textiles, such as leather, cotton, linen and fish skin. Novel bio-based materials include a range of intermediate materials (e.g. building blocks and polymers) that are used to produce a wide range of bio-based products, including bio-based plastics, bio lubricants and solvents (Gomez San Juan, Bogdanski and Dubois, 2019).

Bio-based plastics or bioplastics – Plastics derived fully or partially from biological materials, such as cellulose, potato or corn starch, sugar cane, maize, and soy, instead of fossil-based. They can be engineered to be biodegradable or compostable, or they can be designed to be structurally identical to petroleum-based plastics, in which case they can last in the environment for the same period of time (UNEP, 2023).

Bio-based products – Bio-based products refer to products that are wholly or partly derived from biomass and other biological resources, which are not used for food, feed and fuel. Many bio-based products are not new, such as pulp and paper, timber for construction, bio-based cosmetics and fibres for clothing (Gomez San Juan, Bogdanski and Dubois, 2019).

Biocatalysis – The use of enzymes to improve the efficiency of chemical reactions (FAO, 2002).

Biodegradable material – A material that can, with the help of microorganisms, break down into natural components (e.g. water, carbon dioxide or biomass) under certain conditions (UNEP, 2023).

Biodiversity – The variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic systems and the ecological complexes of which they are part, including diversity within species, between species, and ecosystems (Article 2 of the *Convention on Biological Diversity*, 2011).

Bioenergy – All energy derived from biofuels (Gomez San Juan, Bogdanski and Dubois, 2019).

Bio-engineering, Bioengineering or biological engineering– the application of engineering principles and practices (including from chemical, mechanical, and electrical engineering disciplines) to the life sciences (NIST, 2022).

Biofertilizer or biological fertilizer – A biofertilizer is a natural fertilizer that helps to provide all the nutrients required by the plants and to increase the quality of the soil with a natural microorganism environment. For example, the production and use of biofertilizer (e.g. seaweed products; compost) can improve crop yields by using root nodule bacteria (rhizobia), mycorrhizal fungi, and other microorganisms that are able to increase the accessibility of plant nutrients from the soils (FAO, Alliance of Diversity International and CIAT, 2021).

Biofuel – Fuel that is produced from biomass either directly (e.g. wood) or indirectly through the fermentation of sugars (e.g. ethanol) (Gomez San Juan, Bogdanski and Dubois, 2019).

Biogas – Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment. The precise composition of biogas depends on the type of feedstock and the production pathway (IEA, 2020).

Bioinformatics – the application of computational approaches for the processing and analysis of biological data to make biological discoveries and/or predictions. Bioinformatics may encompass computer science, biology, statistics, mathematics and/or engineering to interpret biological data (NIST, 2022).

Bio-based inputs or bioinputs – Products of plant, animal or microbial origin capable of improving the productivity, quality and/or health of crops (Bullor *et al.*, 2023).

Biological resources or bioresources – Resources that include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity (Article 2 of the *Convention on Biological Diversity*, 2011).

Biomass – Material that can be based on plant or animal life, encompasses, but is not limited to, agricultural crops and trees, including dedicated energy crops, food, feed and fibre crop residues; aquatic plants and animals, algae, fish bones and other fish residues;

forestry and wood residues; agricultural waste, including animal manure; processing by-products and any other non-fossil organic material; microorganisms, such as bacteria (Gomez San Juan, Bogdanski and Dubois, 2019).

Biomanufacturing – Use of biological systems to develop products, tools, and processes at commercial scale (NIST, 2022).

Biomass residues – Agricultural residues from crop and livestock production and fisheries, and wood residues from forest harvesting, forest plantations and wood processing. Other residues include agro-industrial residues from food processing and bio-industrial residues from the processing of other bioproducts (Gomez San Juan, Bogdanski and Dubois, 2019).

Biomass-based value web – The extension of the concept of the biomass value chain to encompass the links that are created within and between value chains as a result of the cascading use and the joint use of biomass. As the degree of recycling and the cascading use of biomass in the bioeconomy increases, especially during the processing stage and the marketing of bioproducts, different value chains will merge, and it will be no longer sufficient to analyse value chains by using a conventional, linear approach that largely focuses on a single product (Gomez San Juan, Bogdanski and Dubois, 2019).

Biomonitoring – The use of living organisms to assess environmental contamination or pollution by measuring accumulation of chemicals in organism tissues or by assessing biomarkers of exposure on indicator species (FAO and UNEP, 2021).

Biopharming – The use of genetically transformed crop plants and livestock animals to produce valuable compounds, especially pharmaceuticals (FAO, 2002).

Bioprocessing or bioproduction – Use of innovative, efficient, and bioengineered microorganisms, and fermentation technologies for conversion of renewable biomass into bioproducts such as food, feed, pharmaceuticals, plastics, and energy.

Biopesticide or biological pesticide – There is no globally agreed use of terms or definition of biological pest control agents or biopesticide but these terms usually include products with active substances that are based on microbials, botanicals or semiochemicals (FAO and WHO, 2024).

Bioproduct – The term "bioproduct" encompasses all products made from biological resources, and includes food, feed, biofuels and bio-based products (Gomez San Juan, Bogdanski and Dubois, 2019).

Bioprospecting – Bioprospecting or biodiversity prospecting is the systematic search for biochemical and genetic information in nature to develop commercially valuable products for pharmaceutical, agricultural, cosmetic and other applications (UNDP, 2018).

Biorefinery – A bio-industrial plant that is engaged in "the sustainable processing of biomass into a spectrum of marketable bio-based products and energy" (De Jong and van Ree, 2009).

Bioremediation – the process whereby contaminants are biologically degraded under controlled conditions that enhance plants' or microorganisms' growth and enzymatic activities (FAO *et al.*, 2020).

Biosafety – A set of measures or actions addressing the safety aspects related to the application of biotechnologies and to the release into the environment of transgenic plants and other organisms, particularly microorganisms, that could negatively affect plant genetic resources, plant, animal or human health, or the environment (UNEP, 2007).

Bioscience – A broad field that is divided into two areas: biological sciences (i.e. the study of life and living organism, their life cycles, adaptations, and environment, and biomedical sciences) – the study of the human system of cells, organs, and system functions.

Biosecurity – A set of measures and practices designed to protect against the introduction and spread of infectious diseases, pathogens, or harmful biological agents within a particular environment, whether they affect humans, animals, or plants (FAO, 2016).

Biosynthesis – Production of chemical compounds from simpler substances, reactions usually carried out in living cells (Darzins, A., Pienkos, P. and Edye, L., 2010).

Biotechnology – Means any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use (CBD, 1992).

Biotrade – Activities associated with the collection and production, transformation and commercialization of goods and services derived from native biodiversity (genes, species and ecosystems) under the criteria of environmental, social and economic sustainability (UNCTAD, 2024).

Biowaste or organic waste – Waste containing carbon compounds derived from animal and plant materials (EEA, 2024).

By-products – Waste streams from a manufacturing process or chemical reaction. They are materials that are not considered to be the principal product or service (Gomez San Juan, Bogdanski and Dubois, 2019).

Cascading use of biomass – A process that involves the reuse of residues and the recycling of materials across the value chain. In a cascading approach, the biomass is processed into a bioproduct that is used at least once more (single-stage use) or several more times (multi- stage use), either for materials or energy, before disposal. A differentiation can be made between cascading-in-value, cascading- in-function and cascading-in-time, depending on the preferences for the sequence in the use of biomass (Olsson *et al.,* 2016; De Schoenmakere *et al.,* 2018). However, the choice in the sequence is context-specific and should be decided through an inclusive local multistakeholder process (Gomez San Juan, Bogdanski and Dubois, 2019).

Catalysis – The process of increasing the rate of a chemical reaction by the addition of a substance that is not itself changed by the reaction (the catalyst) (FAO, 2002).

Co-products – Any of two or more products coming from the same unit process or product system (EC, 2024).

Ecosystem – A system in which the interaction between different organisms and their environment generates a cyclic interchange of materials and energy (EC, 2024).

Ecosystem services – The benefits people obtain from ecosystems. These include provisioning services such as food and water, regulating services such as flood and disease control, cultural services such as spiritual and recreational benefits, and supporting services such as nutrient cycling that maintain conditions for life on Earth (MEA, 2005).

Feedstock – A raw material going into a chemical process or plant as input to be converted into a product (Darzins, Pienkos and Edye, 2010).

Gene editing – Techniques used by scientists to correct or to introduce specific mutations at a particular site (locus) within the DNA of an organism. The techniques used to make these site-specific corrections or directed mutations (base substitution, addition or deletion) include CRISPR-Cas9 gene/genome editing and transcription activator-like effector nucleases (TALENs). Genome editing may be used interchangeably with gene/genome editing (FAO, 2020).

Industrial biotechnology – The application of biotechnology to the eco-efficient production and processing of chemicals, materials and bioenergy (OECD, 2011).

Microbiota – The ecological community of microorganisms or microbes (Gomez San Juan, Bogdanski and Dubois, 2019).

Microbiome – The combined genetic material of all microorganisms living in a given ecosystem, including in the human body (FAO, 2019).

Nutraceutical – Food, food additive, or extract of a food marketed to have a physiological benefit or provide protection against a chronic disease (Darzins, Pienkos, and Edye, 2010).

Polymer – A chemical compound consisting of repeating monomers, a class of molecules that can bond in long chains (Gomez San Juan, Bogdanski and Dubois, 2019)

Soil microbiota – The living bacteria, archaea, fungi, algae, and protozoa inhabiting the soil. The soil microbiome refers to these microorganisms, as well as "their theatre of activity", meaning the microbial structures, metabolites, mobile genetic elements (e.g. viruses and phages), and relic DNA mobile genetic elements (viruses, phages), in their habitat (Berg *et al.*, 2020).

The Knowledge-based economy – The application of the knowledge of life sciences in new, sustainable, environmentally friendly, and competitive products (Carrez *et al.*, 2010).

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Appendix 2. Bioeconomy dedicated strategies: definitions, approaches and objectives

A well-developed dedicated bioeconomy strategy adopts a holistic approach, in which the context will provide valuable information about how the bioeconomy brings together the sectors of wider economy (e.g. its priority areas of research and progress, action plan activities, and monitoring and governance oversight). To understand why countries and regions engage in developing a bioeconomy, it is helpful to consider: what objective countries want to achieve? Why prioritize the bioeconomy over alternative approaches? What are the driving forces, objectives, and key focus areas?

The FAO Dashboard on bioeconomy brings together all national and regional definitions, objectives, activities and governance aspects. This information is summarized and elaborated on throughout this section. It is organized by continent, in alphabetical order, starting by regional perspectives and then national ones.

AFRICA: BIOECONOMY PERSPECTIVES

South Africa, which was the first African country with a national dedicated bioeconomy strategy, adopted its in 2012. The East African Community (The Republic of Burundi, the Democratic Republic of Congo, the Republic of Kenya, the Republic of Rwanda, the Republic of South Sudan, the Republic of Uganda, and the United Republic of Tanzania) published a regional dedicated bioeconomy strategy in 2021. The members of this intergovernmental Organization are also moving towards the developing of national dedicated strategies, and more countries are currently in the process of joining the Organization (e.g. the Federal Republic of Somalia) (EAC, 2024). In 2024, Namibia launched the Namibia Sustainable Bioeconomy Strategy, developed with the technical and financial support of FAO.

EAST AFRICAN COMMUNITY

The East African Science and Technology Commission – an official body of the East African Community – has promoted bioeconomy development on a regional level. The countries covered are The Republic of Burundi, the Republic of Kenya, the Republic of Rwanda, the Republic of South Sudan, the Republic of Uganda, and the United Republic of Tanzania (EAC, 2022).

Bioeconomy in 2021 is defined as:

> "the sustainable production and exploitation of biological resources and knowledge to support (i) a diversified industrial sector producing a range of bio-based products including high-quality foods, feeds, chemicals, pharmaceuticals, textiles, construction products, etc., and (ii) protection of ecosystem services and mitigation of climate change. It is an economy which puts innovation in bio-based products, processes, and business models at the center and a bio-based circular economy as the organism framework." (EAC, 2022).

OBJECTIVES

Strategic direction focuses on the creation of new bio-based products that add value at the local level and/or use resources in novel, innovative, and sustainable ways. Specifically, the scope of the Strategy covers optimization and innovative use of biomass and biological resources produced from agriculture, aquaculture, forestry, and bioprospecting activities, and includes alternative sources of food and feed, health, and bioenergy products.

PRIORITY AREAS

- Food security and sustainable agriculture: a. Value addition to food crops, livestock, and microbial products; b. Novel food and feed products and c. Bio-based agricultural inputs.
- Health and wellbeing: a) bio-based pharmaceuticals, b) bio-based traditional medicines, and c) bio-based cosmetics and well-being products.
- Bio-based industrial development: a) bio-based and biodegradable packaging materials, b) bioprocessing enzymes, c) bio-based construction materials, d) bio-based textile fibres, and e) renewable bio-based oils.
- Sustainable energy: a) biomass briquettes and pellets as alternatives to charcoal and fuelwood, b) production of biogas from organic waste, and c) advanced biofuels.

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ACTIVITIES

The development of a modern bioeconomy in East Africa has significant potential to support several critical development goals and targets for the region, and will help deliver the following outcomes:

1. Sustainable industrialization, job creation, and green growth
2. Improved food security
3. Improved health
4. The creation of new bio-based products
5. Linking farmers and bio-entrepreneurs to market opportunities
6. Creating new forms of clean sustainable modern bioenergy
7. Protecting the environment

GOVERNANCE

Success depends on the ability of East African Community Policymakers to create a suitable environment by examining regulatory frameworks for intellectual property, biosafety, access to and use of genetic resources, and ethics of biosciences and industrial standards. Effective governance requires interdisciplinary assessments from diverse scientific disciplines. To ensure global standards on bio-based products, an independent certifying and testing body must be put in place. Policies must be based on a deep understanding of the region's needs and aspirations and translated into practices that reflect local contexts and priorities.

NAMIBIA

Namibia's National Bioeconomy Strategy, developed with the technical and financial support of FAO, focuses on leveraging the country's rich biodiversity to drive sustainable economic growth, improve quality of life, and enhance resilience against climatic and economic challenges. The strategy aligns with Namibia's Vision 2030 and National Development Plans, aiming to capitalize on the bioeconomy's potential across sectors such as agriculture, health, and natural resource management (Namibia, 2024).

Bioeconomy in 2024 is defined as:

> "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." (Namibia, 2024).

OBJECTIVES

- To create value-addition platforms for bio-based products: promote and support bio-based indigenous products and services, enhance products from indigenous biological resources, utilize high-performing crops and process local fresh produce, and develop value chains for non-timber forest and wildlife products.
- To contribute towards environmental sustainability: Advance climate-smart agriculture practices, promote fossil-free technologies and ecosystem monitoring, and foster sustainable use of natural resources.
- To improve bio-based products through research, development and innovation (RDI): Strengthen research in agricultural and health biosciences, co-create products with rural communities, and promote socio-economic-driven research on value addition.
- To create awareness on bioeconomy in different sectors: Valorize indigenous products and services, educate on indigenous resource profiles, and integrate bioeconomy in sectoral policies.

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PRIORITY AREAS

- Agriculture: Increase production and resilience through innovative crop varieties, livestock breeds, and post-harvest loss mitigation.
- Health: Develop local bio-solutions like diagnostic tools and vaccines, integrating indigenous medicinal plants into healthcare.
- Natural Resources Management: Enhance conservation, sustainable resource use, and environmental protection, balancing ecological sustainability with economic development.
- Cross-cutting Issues: Build infrastructure, capacity, and value chains for sustainable bioeconomy activities, focusing on rural community empowerment and resource utilization.

ACTIVITIES

The strategy is complemented by an action plan, which sets for each strategic objective and related activities quantitative targets, covering the entire timeframe of the document.

GOVERNANCE

The governance structure of Namibia's National Bioeconomy Strategy is centred around the National Commission on Research, Science, and Technology (NCRST), which coordinates the implementation of the strategy. The BMWG was established to provide technical support during the formulation and development of the strategy. The BMWG consists of 24 entities, including 9 government ministries, 5 private companies, 10 non-governmental organizations, public enterprises, and higher education institutions. The strategy's monitoring and evaluation framework includes the performance indicators related to biomass production in agriculture, forestry, and fisheries; the biomass processing indicators in the food, feed, and beverage industry, the material used, as well as the biomass energy use. Furthermore, some performance indicators will measure the progress in terms of inputs, outputs, outcomes, and the impact of the biomass-based services in logistics, transport, retail, research, and tourism.

SOUTH AFRICA

South Africa has distinguished itself among all African countries by being the first to adopt a dedicated national bioeconomy strategy, to transition towards a knowledge-based bioeconomy. It coordinates the various research, development, innovation, and funding activities of trade, industry, health, medical, agriculture, forestry, fisheries, and environmental sectors within a high-level framework. This holistic approach allows for the monitoring of bioeconomic performance (South Africa, 2013).[15]

Bioeconomy in 2013 is defined as:

> "activities that make use of bioinnovations, based on biological sources, materials, and processes to generate sustainable economic, social, and environmental development." (South Africa, 2013).

OBJECTIVES

1. Make the country more competitive internationally, especially in the industrial and agricultural sectors
2. Create more jobs
3. Enhance food security
4. Create a greener economy as the country shifts towards a low-carbon economy
5. Integrate "technology-push and market-pull" to enhance socio-economic development

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15 https://www.gov.za/sites/default/files/gcis_document/201409/bioeconomy-strategya.pdf

PRIORITY AREAS

The strategy focuses on research and development in various fields such as agriculture, industry, health, the environment, and indigenous knowledge. It aims to leverage the country's rich biodiversity and capture niche consumer markets for natural products and plant-based medicines. The strategy also emphasizes the need to support innovation in various areas including biochemicals, bioproducts/materials, bioenergy, bioremediation, biomanufacturing, bioprocessing, biorefineries, biocatalysts, bioprospecting, industrial biotechnology, water scarcity, and wastewater treatment. The approach is not limited to biotechnology but involves cross-sectional technologies and knowledge areas such as information and communication technologies, nanomaterial research and manufacturing, bio-entrepreneurship, social sciences, and intellectual technology management.

ACTIVITIES

Support is focused on research, de-risking research, development and innovation, value chain upscaling, and pilot demonstrations. It includes a plan to develop several facilities, including a bio-manufacturing industry development centre, a biorefinery industry development facility, a supercritical carbon dioxide encapsulation facility, an industrial biocatalysts hub through the work of the Council for Scientific and Industrial Research (CSIR), the Technology Innovation Agency (TIA) and its Umbogintwini Bioprocessing Platform.

GOVERNANCE

TIA plays an important role in the implementation of the bioeconomy strategy. The goal is to establish a strong knowledge base by training and educating scientists, engineers, and technicians along the bioeconomy value chains so that they can convert diverse science-based biotechnologies into innovative bioproducts. Fostering international partnerships to help expand and improve research and innovation is also encouraged.

The success of the bioeconomy strategy depends on well-coordinated efforts and effective governance oversight. To ensure this, various committees have been established to monitor and manage the Strategic Health Innovation Partnership Program, the Agricultural Bio-innovation Partnership Program, the Indigenous Knowledge Systems area, and the Industry and Environmental Programme. The national strategy includes a broad range of indicators.

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LATIN AMERICA AND THE CARIBBEAN: BIOECONOMY PERSPECTIVES

The concept of bioeconomy has gained significant political importance in Latin America and the Caribbean in recent years, but the adoption of dedicated national bioeconomy strategies has been slow. However, some countries have been advancing the development of bioeconomy-related strategies (e.g. bioenergy and biotechnology strategies). Argentina focuses on biotechnology, bioenergy, bio-inputs, and biomaterials, Paraguay emphasizes high-tech solutions alongside biodiversity conservation. These strategies aim to promote sustainable development and green growth by taking advantage of the large quantity of natural resources available in each country. Brazil, Colombia and Costa Rica are currently the only countries in the region that have published and enacted a national dedicated bioeconomy strategy. However, Argentina, Ecuador, Mexico, Paraguay and Uruguay have announced the development of national dedicated bioeconomy strategies. Ecuador has published in 2024 its national White Paper on Bioeconomy (Garcìa, 2024), which lays the foundations of the bioeconomy in the country and "represents a crucial step in building a National Strategy for Sustainable Bioeconomy" (Ecuador, 2024).

BRAZIL

The Brazilian National Bioeconomy Strategy aims to coordinate and implement public policies for the development of the bioeconomy in collaboration with civil society and the private sector. The strategy emphasizes sustainable, regenerative, and biodiversity-conserving approaches guided by scientific and traditional knowledge (Brazil, 2024).

Bioeconomy in 2024 is defined as:

> "A productive and economic development model based on justice, ethics, and inclusion, generating efficient products, processes, and services through sustainable use, regeneration, and conservation of biodiversity, focusing on value addition, job creation, sustainability, and climate balance." (Brazil, 2024).

OBJECTIVES

The strategy promotes national, regional, and local development using sustainable biological resources to ensure water, food, and energy security. It aims to enhance forest and sociobiodiversity economies, strengthen the competitiveness of bio-based production, develop innovation ecosystems, establish a National Bioeconomy Information System, create financial and economic instruments to support bioeconomy, and expand market access for bio-based products.

PRIORITY AREAS

- Stimulation of economic and productive activities that promote the sustainable use, conservation, regeneration, and valorization of biodiversity and ecosystem services;
- decarbonization of productive processes and promotion of biomass production and processing systems that do not involve the conversion of original native vegetation;
- promotion of bio industrialization in line with industrial policy;
- encouragement of regenerative agriculture, productive restoration, recovery of native vegetation, sustainable forest management and production, especially of healthy food systems;
- respect for the rights of Indigenous Peoples and traditional communities to self-determination and the use and traditional management of their territories;

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- reduction of inequalities, aiming at regional development;
- encouragement of the inclusion of women and young people in the bioeconomy;
- fair and equitable sharing of benefits from access to genetic resources and associated traditional knowledge;
- expansion and improvement of the innovation environment based on biodiversity assets, agricultural and forestry production, and installed industrial capacities for the development of high-value-added products, technological densification, and businesses suitable for different scales and productive models;
- professional training and capacity building, promotion of entrepreneurship, and generation of new jobs for the different segments of the bioeconomy;
- encouragement of research, technological development, innovation, and production activities, to integrate scientific and traditional knowledge in partnership with science and technology institutions and public and private companies;
- assessment of the risks, opportunities, and impacts of scientific and technological development and productive activities of the bioeconomy; and
- articulation and cooperation among federal entities and between the public, private, academic sectors, and civil society.

ACTIVITIES

The National Bioeconomy Development Plan will outline resources, actions, responsibilities, goals, and indicators. It will focus on financial instruments, regulatory frameworks, data and knowledge, sustainable infrastructure, markets, value chains, and professional education and innovation.

GOVERNANCE

Implemented by the Union in cooperation with states, municipalities, the Federal District, civil society, and private entities. The National Bioeconomy Commission, formed by the Ministries of Environment and Climate Change, Development, Industry, Commerce, Services, and Finance, will develop the National Bioeconomy Development Plan, aligning with various sectoral policies. The Ministry of Environment and Climate Change will implement the National Information and Knowledge System on Bioeconomy, a system for collecting, processing, and storing information and knowledge about bioeconomy and intervening factors, to support the implementation of the Strategy and the Development Plan.

COLOMBIA

Colombia has developed a comprehensive bioeconomy strategy aimed at making the country an innovative and competitive global leader in intelligent, circular, and sustainable use of its mega-biodiversity, ecosystem services, and biomass. By 2030, the goal is to generate comprehensive well-being for Colombians through these initiatives (Colombia, 2020).

Bioeconomy in 2023 is defined as:

> "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." (Colombia, 2020).

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OBJECTIVES

Colombia aims to advance high-value-added bioeconomy products and processes through the sustainable use of biomass and biodiversity. Objectives include boosting domestic and international market demand, enhancing investment and partnerships, strengthening regulatory frameworks, improving research capacities, contributing to decarbonization, and preserving biodiversity and ecosystem services.

PRIORITY AREAS

The strategy emphasizes:

1. Sustainable utilization of continental and marine biodiversity and ecosystem services
2. Leveraging biodiversity
3. Productive and sustainable agriculture
4. Biomass and green chemistry that maximize value from biomass and minimize waste
5. Advanced technologies for health and well-being.

ACTIVITIES

Colombia's bioeconomy aims to significantly boost economic growth and employment by 2030. With a target of contributing 10 percent to GDP, the strategy seeks to create 2.5 million new jobs and foster innovation. Over 500 bioproducts will be developed, expanding into new markets domestically and internationally. Additionally, support will be provided to all 32 Departments and the Capital District of Bogotá to strengthen value chains and clusters and drive bioeconomy development nationwide.

GOVERNANCE

The Ministry of Science, Technology, and Innovation serves as the lead of an interministerial body to ensure the implementation of the bioeconomy strategy.

COSTA RICA

Costa Rica aims to utilize biological resources, knowledge, and innovation for sustainable development. It emphasizes conservation, restoration, and sustainable use of resources, promoting social inclusion –with a focus on gender and Indigenous Peoples – and a post-fossil-resources society. Strategic objectives include rural development, ecosystem enhancement, and urban bioeconomy initiatives. It addresses sustainable agriculture, biodiversity, forestry, clean energy, climate change, and sustainable tourism (Costa Rica, 2020).

Bioeconomy in 2020 is defined as:

> "the production, utilization, conservation, and restoration of biological resources, including related knowledge, science, technology, and innovation to provide information, products, processes, and services in all economic sectors aiming towards a sustainable bioeconomy." (Costa Rica, 2020).

OBJECTIVES

- Make Costa Rica a model country in sustainable development by taking advantage of its biological resources to promote social inclusion and equity, balanced territorial development, conservation, knowledge, the sustainable use of biodiversity, and national competitiveness.

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- Make the bioeconomy one of the pillars of the productive transformation of the country by promoting innovation, value creation, diversification, and the sophistication of the country's economy; applying the principles of the circular bioeconomy; and decarbonizing production and consumption processes.
- Promote the convergence between the country's wealth in biological resources and the use of national capacities in biological sciences for the valorization of that wealth.

PRIORITY AREAS

The strategy outlines five key areas of focus:

1. Bioeconomy for rural development
2. Biodiversity and development
3. Biorefinery of residual biomass
4. Advanced bioeconomy
5. Urban bioeconomy and green cities

The primary emphasis is on focus area 3, which aims to promote the comprehensive use and valorization of residual biomass from agricultural, agro-industrial, forestry, and fishing processes to produce energy and bioproducts. Biorefining will be used to create new value chains and networks in primary production. Bioenergy generated from residual biomass will also be used as an alternative for private consumption on farms and rural households. The production of bioproducts and bio-based materials should result in the production of biofertilizers and proteins for animal feed and the replacement of fossil-based products. To achieve an advanced bioeconomy, biotechnology, nanotechnology, and digital technologies, along with their convergence and sustainable use of biological resources, including omics, synthetic biology, biochemical engineering, green chemistry, bioinformatics, diagnostics, and biomonitoring will be developed.

ACTIVITIES

The focus of support is on:

- investing in education, training, and capacity development to build a knowledge-based society and ensure quality education and universal access;
- promoting environmental education through regional platforms for virtual tourism, and internship programmes with companies for youth and women who are interested in bio businesses;
- stimulating local markets for bioeconomy goods and services by providing new incentives, regulations, and financing options for all stages of the value chain;
- empowering the entire population by supporting networks at local, regional, national, and international levels;
- prioritizing strengthening existing mechanisms that manage ecosystem services in forestry, biodiversity, and ecotourism; and
- enhancing capacity in intellectual property management, licensing, and other mechanisms to protect knowledge.

GOVERNANCE

A National Bioeconomy Council serves as a multistakeholder body to ensure the implementation of the bioeconomy strategy. The Council has a technical secretariat and ad-hoc groups that monitor and evaluate the implementation of the strategy, and promote good governance, policy coherence, and effectiveness. The Council will also develop a 10-year action plan to monitor and evaluate the strategy's implementation.

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NORTH AMERICA BIOECONOMY PERSPECTIVES

The United States is the only country in North America with a dedicated and holistic national bioeconomy strategy.

UNITED STATES OF AMERICA

With the release of its National Bioeconomy Blueprint in 2012, the United States became the first country to recognize biotechnology as a significant driver of the bioeconomy. It placed an emphasis on biotechnology and biomedicine. Afterwards, the agricultural strategy (2014 to 2018) developed by the US Department of Agriculture (USDA), even if it did not specifically address the bioeconomy, expanded the government's efforts to procurew bio-based products through the BioPreferred Program. It promotes the use of bio-based products through a government procurement programme and a voluntary certification and labelling programme. It has become one of the key support instruments for the US bioeconomy. Since its launch in 2011, nearly 9 000 bio-based products have been certified and labelled (as of 2023) (Boldt, 2023). More recently, an Executive Order, "Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy", was released on 12 September 2022, outlining a new vision for a government-wide approach to promote the national bioeconomy (United States of America, 2022).

The bioeconomy is defined as:

> "economic activity derived from biotechnology and biomanufacturing". However, a follow-up brief to the Executive Order created by the Congressional Research Service in 2022 defines the bioeconomy as "the portion of the economy based on products, services, and processes derived from biological resources (e.g., plants and microorganisms)." The National Academies recommended in their 2020 report, *Safeguarding the Bioeconomy,* that the bioeconomy should be defined as "economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances in engineering and in computing and information sciences." (United States of America, 2022). As a result of the 2022 executive order on the bioeconomy, the National Institute of Standards and Technology (NIST) created a lexicon around the bioeconomy and defined the bioeconomy as "economic activity derived from the life sciences, particularly in the areas of biotechnology and biomanufacturing, including industries, products, services, and the workforce." (NIST, 2022). While all these definitions are similar, each definition lacks something the other definitions include, thus resulting in a lack of consensus.

OBJECTIVES

The Executive Order delineates a bioeconomy driven by biotechnology and biomanufacturing, which is pivotal in driving economic growth, creating jobs, and enhancing quality of life and environmental sustainability. Building on lessons learned from the COVID-19 pandemic, it aims at harnessing biotechnology in developing life-saving solutions and tackling broader issues such as climate change, energy, food security, and supply chain resilience. To this end, investments in foundational scientific knowledge (e.g. genetic engineering, data analytics, and techniques that can scale-up production) are seen as crucial. However, to leverage the transformative power of biotechnology and safeguard societal well-being and global prosperity, the executive order envisions measures be taken to mitigate biological risks, promote biosafety and biosecurity, and safeguard against exploitation by adversaries.

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PRIORITY AREAS

The country's bioeconomy priorities, under the current administration's strategy, entail:

- increasing federal investment in pivotal biotechnology and biomanufacturing research areas to align with societal objectives;
- cultivating a robust biological data ecosystem while maintaining security and responsible research conduct;
- enhancing domestic biomanufacturing capacity and expediting research translation into practical applications;
- incentivizing sustainable biomass production and implementing climate-conscious strategies for agricultural and forest stakeholders;
- broadening market avenues for bioenergy and bio-based products;
- fostering a diverse and proficient workforce;
- simplifying regulations for efficient and transparent utilization of biotechnology products; prioritizing biological risk management throughout research and development efforts;
- establishing standards and metrics to gauge the bioeconomy's progression and ensure equitable and ethical growth;
- fortifying the bioeconomy against potential threats and vulnerabilities; and
- engaging in international collaboration to advance safe and secure biotechnology research, innovation, and product development.

ACTIVITIES

The Executive Order is prioritizing advancing its bioeconomy through coordinated federal investment in biotechnology research and development, fostering a secure biological data ecosystem, and expanding domestic biomanufacturing. Sustainable biomass production is promoted, alongside market expansion for bioenergy and bio-based products. Efforts include workforce training, regulatory streamlining, and emphasizing biological risk management. International engagement enhances cooperation while safeguarding technology leadership and economic competitiveness.

GOVERNANCE

The Executive Order mandates federal agencies to submit reports within 180 days, detailing strategies for achieving the specified goals. These reports must emphasize the necessity for basic research and technological development in each sector and identify opportunities for collaboration between the public and private sectors. So far, five reports have been published. This includes the 2023 document, *Bold Goals for U.S. Biotechnology and Biomanufacturing: Harnessing Research and Development to Further Societal Goals*, released by the White House Office of Science and Technology Policy. The 2022 report, *Biomanufacturing to Advance the Bioeconomy* identifies three specific weaknesses currently impeding the country's progress and which need to be addressed: inadequate production capacities, regulatory uncertainties, and an outdated national strategy. The 2023 report, *Developing a National Measure of the Economic Contributions of the Bioeconomy* examines the feasibility, scope, and costs of developing a bioeconomy satellite account. With the *Building the Bio workforce of the Future* action plan released in 2023, the nationwide implementation of formal and informal training measures, vocational and technical education, and advanced career pathways in existing programmes in the fields of biotechnology and bio-based production are to be massively promoted. Within 100 days of receiving the final reports, an implementation plan must be developed, integrating the measures outlined in these reports.

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After a two-year period, the involved agencies and departments are required to report on the actions taken and the resources allocated towards advancing the objectives outlined in the Executive Order. In 2024, the USDA published a report, *Building a Resilient Biomass Supply*, that outlines a plan to boost the biomass supply chain for domestic bio-based product manufacturing and market opportunities for small and medium-sized producers, providing job opportunities to rural communities and making progress towards national sustainability goals. The White House also took an important step in bioeconomy governance by launching the National Bioeconomy Board.[16] The Board will work with partners across the public and private sectors to advance societal well-being, national security, sustainability, economic productivity, and competitiveness through biotechnology and biomanufacturing. The Board is co-chaired by the White House Office of Science and Technology Policy (OSTP), the Department of Commerce (DOC), and the Department of Defense. The Board also includes representatives from nine additional federal departments and agencies (OSTP, 2024).

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16 https://www.whitehouse.gov/ostp/news-updates/2024/03/22/the-white-house-advances-biotechnology-and-biomanufacturing-leadership-with-the-launch-of-the-national-bioeconomy-board/

ASIA AND THE PACIFIC: BIOECONOMY PERSPECTIVES

The Asia and the Pacific region has a major focus on developing bioeconomy, particularly in high-tech and industry innovations. Emphasis is put on improving human health and medical sectors. The bioindustry is concentrating on developing innovative bio-based products (e.g. marine biodegradable plastic) and establishing centres of excellence for bioeconomy research and experimentation. Only China, Japan, Malaysia, and Thailand have published and enacted national dedicated bioeconomy strategies. However, other countries have developed bioeconomy-related strategies**.** Australia, India, Indonesia, New Zealand, and the Republic of Korea prioritize bioenergy and biofuel production in tandem with high-tech research and innovation. Russia and Sri Lanka emphasize high-tech biotechnology development. India has also announced its intention of developing a national dedicated bioeconomy strategy (India, 2024). It worth noting that, in May 2024, Japan has finalized the revision and update of its bioeconomy strategy (Japan, 2024).[17]

CHINA

China's "14th Five-Year Plan for Bioeconomy Development" (2021–2025) focuses on advancing biomedicine, bio-agriculture, biomanufacturing, and bioinformatics, and strengthening biosecurity and environmental protection. By 2035, China aims to lead the global bioeconomy with advanced technology, a robust industry, resource security, risk control, and comprehensive regulation, fostering innovation and sustainability (China, 2021).

Bioeconomy in 2021 is defined as:

> "an economic system that relies on biological resources and biotechnology to create value and drive economic growth. It involves the sustainable and responsible use of biological resources, including agriculture, forestry, healthcare, energy, and environmental sectors, to produce goods and services that benefit society while maintaining ecological balance." (China, 2021).

OBJECTIVES

China aims at moving towards a bioeconomy of scale by 2025 through the integration of science, technology, and industry for high development. By 2035, the objective is to achieve global leadership, marked by advanced technology, robust industries, and comprehensive bio-risk management frameworks.

PRIORITY AREAS

Key areas of focus include biomedicine, bio-agriculture, bio-manufacturing, and biosecurity. In biomedicine, the emphasis is on developing new drugs and medical equipment to meet healthcare demands. Bio-agriculture aims to modernize agricultural practices through genetically engineered crops and sustainable pest control methods. Bio-manufacturing focuses on eco-friendly biomaterials and energy sources, and biosecurity ensures robust measures are in place to prevent and manage biological threats.

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17 As of the time of publication, an official translation of the updated 2024 strategy was not available; therefore, this publication considers the 2019 strategy.

ACTIVITIES

To achieve its goals, China is investing in biotechnological innovation, with a focus on cutting-edge research in life sciences and genomics. Technologies such as high-throughput sequencing and gene editing are being promoted to drive advancements in biomedicine and agriculture. Industrial development efforts are also underway to cultivate key bio-industries, including biopharmaceuticals, agricultural biotechnology, and bioenergy.

GOVERNANCE

The Chinese government is supporting bioeconomy development through policy initiatives, intellectual property protection, and financial investment. Policies are being implemented to create a conducive environment for bio-innovation, while international collaborations are being pursued to address global bio-security challenges.

JAPAN

Japan adopted its bioeconomy strategy in 2019 with a strong focus on bioindustry, research, and high technology. It is one of the most comprehensive national strategies with regard to digitization, artificial intelligence, and robotics. The Japanese national bioeconomy strategy seeks to holistically cover a range of topics from the circular bioeconomy to the more social and political dimensions. It emphasizes the importance of bio-communities, which are intended as collaborative ecosystems comprising industry, academic institutions, local governments, and other stakeholders (Japan, 2019).[18] It worth noting that, in May 2024, Japan has finalized the revision and update of its bioeconomy strategy (Japan, 2024).

Bioeconomy in 2020 is defined as:

> "A concept of utilizing biotechnology, renewable biological resources in order to expand a sustainable, renewable, and recycling-oriented economic society." (Japan, 2019).

OBJECTIVES

The strategy aims to address several pressing issues, such as climate change, conservation, an aging population, and social challenges. It proposes the use of biotechnology and renewable bioresources, including waste, as tools for achieving economic growth. It also emphasizes the importance of rapid technological innovation, specifically linking biotechnology with digital technologies (e.g. big data and artificial intelligence). The strategy also seeks to strengthen the relationship between science and society and align itself with global efforts related to the conservation and restoration of the environment, food security, and the creation of a recycling society.

PRIORITY AREAS

The strategy is centred around the use of high-performance biomaterials, particularly in the fields of health, medicine, and mobility. It places a strong emphasis on food-based healthcare, biopharmaceuticals, regenerative medicine, cell and gene therapy. The strategy also promotes the use of bioplastics as a replacement for chemical-based plastics, and smart farming technology to tackle climate change and the growing demand for healthy and better-tasting food. The strategy also supports organic waste and organic wastewater recycling, biofoundries for engineered biology, microbes and fermentation, and the use of wooden architecture and smart forestry.

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18 https://www.dwih-tokyo.org/files/2020/10/bio2020_honbun_en_rev-1.pdf

ACTIVITIES

- Encourage "open" innovation by promoting data sharing between national research institutions and industry to develop markets and foster international and regional collaboration through demonstration projects.
- Establish two international biocommunities (Tokyo and Osaka) and six regional communities (Hiroshima, Hokkaido, Fukuoka, Najanoka, Okinawa, and Tsuruoka) to attract scientists and investors by creating advanced research incubation centres and biofoundries. These biocommunities represent a good practical example of how a country is working to provide more evidence and therefore strengthen the realization of the bioeconomy (see Case Study in Box 4).

GOVERNANCE

The government's Bio Strategy Taskforce, made up of several federal agencies, is responsible for enhancing its strategic command function by moving from a decentralized to a centralized connected approach. This approach will bring resources together in a synergistic way, particularly in the areas of health and medical bio-strategies. Additionally, the government is looking to improve its ability to review markets, policies, and regulations governing investors and funding agencies.

MALAYSIA

Malaysia had the distinction of being the first Asian country to develop a dedicated bioeconomy strategy when the government launched its National Bioeconomy Policy in 2015. After a number of different bioeconomy initiatives, the currently bioeconomy strategy is as 15-year plan to promote biotechnology as a key driver of economic growth in three main areas: capacity building, the commercialization of research and development, and internationalization. The strategy aims to advance biotechnology in three main sectors: agriculture, healthcare, and industrial manufacturing (Malaysia, 2021).

Bioeconomy in 2012 is defined as: "

> all economic activity that is derived from the continued commercial application of biotechnology and the production of renewable biological resources and their conversion into food, feed, chemicals, energy, and healthcare wellness products via innovative and efficient technologies." (Malaysia, 2021).

OBJECTIVES

The strategy is focused on the bio-based industry and economic sectors that produce, manage, and utilize biological resources. These sectors include agriculture, forestry, fisheries, food production, healthcare, chemicals, and renewables. The main objectives of this strategy are to enhance domestic biotechnology and bio-based industries, create new job opportunities, promote the green economy, reduce the national carbon footprint by 40 percent, and improve the health and well-being of the people by reducing healthcare costs.

PRIORITY AREAS

The three focus areas are agriculture, healthcare, and industry. Agriculture will prioritize bio-based feeds, vaccines, fertilizers, and pesticides. Healthcare will prioritize high-value food varieties and bioingredients. Industry will prioritize bio-based raw materials such as palm oil for industrial applications.

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ACTIVITIES

Develop a biopark/biohub concept to establish infrastructure and support a sustainable ecosystem for research and development. This concept includes a "plug-n-play model" for biorefineries and biochemical plants and develops talent and entrepreneurship to help the biotech sector by establishing education and capacity. Commercialization measures will be implemented to enhance value-adding biotechnology and life science activities.

GOVERNANCE

The Bioeconomy Corporation, a public agency, is responsible for implementing the bioeconomy strategy. Targets are continuously monitored against key performance indicators. The strategy includes a system for automatic monitoring and evaluation using an analysis of blockchain data and artificial intelligence. 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.

THAILAND

Thailand follows a comprehensive approach to biotechnology and knowledge-based industries that use various applications in medical, agricultural, aquatic, and industrial fields. Using a 10-year action roadmap, the country plans to establish a value-based, innovative, and technology-driven economy. It aims to promote Thailand as a biohub in Asia with a focus on bioplastics, biochemicals, and biopharmaceuticals. Bioeconomy in Thailand takes the form of a bio, circular, green economic model, and has been implemented since 2019 through a dedicated Bio-Circular Green Economy Action plan (Thailand, 2022).

Bioeconomy is not defined but is an economic model that promotes food and agriculture, medical and wellness, bioenergy, biomaterials, biochemicals, bio-tourism, and a creative economy (Thailand, 2022).

OBJECTIVES

The Bio-Circular Green Bioeconomy strategy has the objective of spreading economic growth while emphasizing biodiversity and biotechnology as key factors for the bioeconomy. Its goal is to establish an innovative and value-based national economy and enhance its competitiveness on an international level.

PRIORITY AREAS

The strategy targets agriculture, the medical and pharmaceutical sector, energy, and tourism for the promotion of sustainable and inclusive growth.

ACTIVITIES

Various fields such as microbiota, omics, bioprocessing engineering, gene editing, and synthetic biology will be prioritized for research and innovation. To encourage international research collaboration, a global forum will be established. Additionally, infrastructure will be enhanced by creating a national biobank to collect, preserve, and utilize bioresources. Investment and innovation will focus on industries in the Eastern Economic Corridor of the Innovation Hub.

GOVERNANCE

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.

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EUROPE AND CENTRAL ASIA: BIOECONOMY PERSPECTIVES

In 2012, same year of the release of the United States Bioeconomy Blueprint and South Africa bioeconomy strategy, the European Commission established the first dedicated regional bioeconomy strategy. This led to the development of dedicated-bioeconomy strategies across Member States of the European Union. Strategies have been developed by Austria, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, the Kingdom of the Netherlands, Nordic Region (Denmark, Finland, Iceland, Norway, Sweden, Faroe Island, Greenland, and Aland), Norway, Portugal and Spain. However, Croatia, Czechia, Hungary, Lithuania, Poland, Slovakia, Sweden, Switzerland and Türkiye have announced their intention of developing a national bioeconomy dedicated strategy.

It is noteworthy that in the European Union around 30 sub-national territories have developed their bioeconomy strategies (EC, 2019). Sub-national strategies are gaining momentum in EU countries. These strategies, which can reflect a bottom-up approach to bioeconomy development and/or a response to the advancement of overarching national bioeconomy strategies, can be effective mechanisms for localized implementation efforts.

AUSTRIA

The Austrian government had established bioeconomy-related policies that were focused on research, before publishing a national bioeconomy strategy in 2019. The strategy is an important part of the Austrian Climate and Energy Strategy, which is aligned with the 2030 Agenda for Sustainable Development and the Paris Climate Agreement (Austria, 2019).

Bioeconomy in 2019 is defined as:

> "an economic concept that aims to replace fossil resources (raw materials and energy sources) with renewable raw materials in as many areas and applications as possible." (Austria, 2019).

OBJECTIVES

The strategy addresses food and water shortages and environmental pollution, by merging technology and ecology. Its goals include reducing greenhouse gas emissions, increasing the use of renewable resources, creating more green jobs, boosting economic development and competitiveness, mobilizing private capital for bioeconomy development, and becoming a leading exporter of innovative, high-value bio-based products and services. The vision of Austria's bioeconomy is to transition from a fossil-based economic system to one based on renewable, biologically sourced materials and energy.

PRIORITY AREAS

The strategy aims to tackle six main areas:

1. Achieving climate targets
2. Reducing dependency on non-renewable raw materials
3. Promoting innovation
4. Promoting economic development
5. Securing and creating jobs
6. Promoting sustainable societal transformation.

The strategy also emphasizes bio-digitization and new communication as the overarching theme.

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ACTIVITIES

The strategy targets innovation across various disciplines, sectors, and institutions to promote cooperation between businesses, science, public administration, and broader society. It also supports research and innovation in the bioeconomy, including basic research at universities, cooperation centres, and industry. Funding programmes are also in place for applied and industrial research.

GOVERNANCE

The Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation, and Technology is responsible for implementing the bioeconomy strategy with the assistance of oversight stakeholders from science, business, and civil society.

ESTONIA

The 2023 Estonian bioeconomy strategy, which emphasizes circularity as an approach to provide added value and optimize resources and focuses on the agrifood sector, seeks to increase the value of agricultural resources, optimize timber processing, improve fisheries and aquaculture practices, and enhance the use of renewable energy (Estonia, 2023).

Bioeconomy in 2023 is defined as:

> "the production of renewable biomass and converting it mainly into food, feed or other bioproducts and bioenergy. Bioeconomy covers agriculture, forestry, fisheries, aquaculture, food, fibre and paper, and partly the chemical, biotechnology, and energy industries." (Estonia, 2023).

OBJECTIVE

Enhancing sustainability by reducing reliance on non-renewable resources and bolstering resource efficiency, to ensure food and raw material self-sufficiency. Through research, innovation, and collaborative models, it seeks to boost exports, attract foreign investment, and elevate the circular bioeconomy's value.

PRIORITY AREAS

The main areas of bioeconomy development in Estonia are:

1. Greater added value from the circular bioeconomy
2. Sustainable resource supply and biodiversity conservation
3. Research and development, innovation and technology
4. Competitive business environments
5. Education, skills and awareness

ACTIVITIES

- promoting alternative raw materials and novel foods, reducing greenhouse gas emissions through alternative feed components, and advancing technologies like synthetic biotechnology and hydroponics;
- utilizing by-products and residues in various industries, along with the chemical valorization of wood, to maximize resource efficiency;
- developing infrastructure for biowaste management and biogas production in tandem with efforts to attract private investment and foster circular bioeconomy networks in the European Union;

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- adapting regulatory frameworks, supporting green procurement, and empowering local development centres to promote regional growth; and
- carrying out circular bioeconomy education initiatives and disseminating its principles to ensure comprehensive awareness and cooperation within communities.

GOVERNANCE

The strategy is overseen by the Ministry of Regional Affairs and Agriculture, which collaborates closely with the Ministry of Climate and other governmental departments. This initiative involves active participation from scientists, entrepreneurs, and various interest groups and receives support from the Estonian University of Life Sciences. No monitoring system is mentioned.

EU BIOECONOMY STRATEGY

The European Commission has been driving the development of bioeconomy in the European Union since 2012, when it launched its first bioeconomy strategy. The 2018 update of the Bioeconomy Strategy accelerates the deployment of a sustainable EU bioeconomy to maximize its contribution to the SDGs and the Paris Agreement. The update also responds to new EU policy priorities, particularly the renewed Industrial Policy Strategy, the Circular Economy Action Plan and the Communication on Accelerating Clean Energy Innovation, all of which highlight the importance of a sustainable, circular bioeconomy to achieve their objectives (EC, 2018a). In the second half of the 2024, with the Hungarian presidency of the Council of the European Union, bioeconomy will be a priority area (HU24EU, 2024).

Bioeconomy in 2018 is defined as:

> "The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources, i.e. agriculture, forestry, fisheries and aquaculture; and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. It cuts across these sectors and systems, interlinking them and creating synergies." (EC, 2018a). It is noteworthy that while biotechnology is at the heart of bio-based processes, health biotechnology and biological medicines are not included in the bioeconomy definition.

OBJECTIVES

1. Ensuring food security
2. Managing natural resources sustainably
3. Reducing dependence on non-renewable resources
4. Mitigating and adapting to climate change
5. Creating jobs and maintaining competitiveness

The strategy tackles challenges like ecosystem degradation, climate change impacts, and resource scarcity. By promoting innovation and sustainable practices, the strategy works to foster a resilient, resource-efficient, and competitive bioeconomy.

PRIORITY AREAS

1. Strengthening bio-based sectors: By intensifying research and investment, promoting sustainable solutions, and addressing regulatory conditions, the European Union aims to modernize industries and combat plastic pollution.

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2. Deploying local bioeconomies: Through strategic planning and pilot projects, the European Union seeks to enhance sustainable food systems, foster innovation in forestry and farming, and exploit ocean farming potential.
3. Understanding ecological limits: By improving knowledge and monitoring, the European Union aims to ensure the bioeconomy operates within safe ecological boundaries and integrates biodiversity benefits into primary production.

ACTIVITIES

The updated strategy comes with an action plan for implementation with concrete measures based on three key priority areas (EC, 2018b). To strengthen bio-based sectors, actions include mobilizing stakeholders, analysing innovation deployment bottlenecks, launching investment platforms, promoting market uptake through standards and labels, facilitating biorefinery development, and creating bio-based substitutes for fossil-based materials. In deploying local bioeconomies, initiatives involve launching a strategic deployment agenda for sustainable agrifood systems, supporting regions and Members in developing their strategies, enhancing education, and developing inclusive bioeconomies in rural, coastal and urban areas. Initiatives include the Urban Bioeconomy Piloting, which will enable 10 EU cities to turn organic waste from into a valuable resource to produce bio-based products. Understanding ecological limits entails enhancing knowledge on biodiversity and ecosystems, enhancing biodiversity benefits in primary production, promoting best practices, and monitoring progress.

GOVERNANCE

The progress of the bioeconomy in the European Union towards its strategic objectives is tracked by the EU Bioeconomy Monitoring System. This system establishes a mechanism to measure the bioeconomy's advancement across the environmental, social, and economic dimensions of sustainability, and is aligned with the SDGs. Launched officially in November 2020, since 2023 the results have been accessible through an interactive dashboard managed by the Knowledge Centre for Bioeconomy (EC, 2019).

FINLAND

The Finnish strategy, similar to the Estonian strategy, harnesses bioeconomy to sustainably increase value addition in an ecologically, socially, and economically sustainable manner and make Finland climate-neutral by 2035 (Finland, 2022). This is in alignment with the Nordic Bioeconomy Programme.

Bioeconomy in 2020 is defined as:

> "an economy that relies on renewable, biological natural resources in a resource-efficient manner to produce food, energy, products, and services." (Finland, 2022).

OBJECTIVES

The strategy's main objective is to increase the value added by the bioeconomy. The aim is to create economic growth and jobs based on sustainable approaches by producing the highest possible value-added products and services. At the same time, the Bioeconomy Strategy also seeks to:

- create competitive and innovative bioeconomy solutions to address global problems;
- generate businesses that promote renewal both for domestic and international markets and improve the well-being of all people living in to Finland;
- increase efficiency in the use of resources, the recycling of materials and the use of production side streams;

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- reduce dependence on non-renewable raw materials, especially those that are fossil-based;
- ensure ecological sustainability, social justice and the capacity of renewable natural resources to renew themselves and generally strengthen bioeconomy competence; and
- strengthen and renew the technological foundations of the bioeconomy.

PRIORITY AREAS

1. Increased value added from the bioeconomy: The strategy aims to boost economic growth and job creation by producing high-value products and services sustainably. This involves increasing resource-efficient use, recycling materials, and reducing reliance on non-renewable resources.
2. Increased competence and broader technology base: Focus is placed on research and digitalization to optimize industrial production, enhance efficiency, and ensure transparency in data transfer.
3. Competitive operating environment: The strategy highlights the importance of a supportive legal and policy environment for bioeconomy investments that can ensure predictability and encourage innovation.
4. Usability and sustainability of bioresources: To maintain the profitability of agriculture, forestry, fishing, and aquaculture while safeguarding ecological sustainability, the strategy works to maximize the potential of biomass reserves and ecosystem services and ensure biodiversity.
5. Increasing value added in different sectors, including the forest, food, energy, water, textiles, and chemical industries: The strategy emphasizes the creation of new value chains and cross-sector collaboration.

ACTIVITIES

Finland's bioeconomy strategy encompasses a wide array of initiatives aimed at fostering innovation, sustainability, and economic growth. Key actions include reforming research to support commercialization of new bioeconomy products, supporting small and medium enterprises and start-ups in scaling bio-based materials, and identifying flagship companies to accelerate ecosystem development. The strategy emphasizes education and training to enhance bioeconomy expertise, and policy and regulatory measures to create a conducive environment. International collaboration is prioritized to leverage research funding from the European Union and participate in global networks. Digitalization plays a crucial role, with investments in digital platforms and big data utilization across sectors. Circular economy integration is promoted through cooperation projects. Resource efficiency and climate change mitigation are addressed through innovative technologies and market development. Specific sectors like textiles, wood, energy, and biogas receive focused attention, as do fisheries, aquaculture, and natural product utilization in tourism.

GOVERNANCE

The governance dimension of Finland's bioeconomy strategy involves coordinated efforts across several ministries, with the Ministry of Economic Affairs and Employment leading the coordination. A steering group and secretariat are appointed to monitor strategy implementation, with involvement from other organizations and stakeholders through a national Bioeconomy Panel. Monitoring and evaluation of the strategy's impacts are conducted using a set of indicators, including value added, investments, exports, and employment, with sustainability assessed using existing ecological, economic, and social indicators. The Ministry of Economic Affairs and Employment oversees the monitoring process, with assessments scheduled periodically. The strategy's update process involves a steering group, coordination secretariat, and the national Bioeconomy Panel, ensuring comprehensive stakeholder engagement and alignment with government objectives.

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FRANCE

The bioeconomy strategy of France aligns with other national holistic strategies that focus on the production of bioresources, their utilization, and their environmental impacts. The strategy outlines a plan that address various topics, such as agroecology, plant-based proteins, biomass mobilization, circular economy, low-carbon development, multi-year energy generation, forestry, biodiversity, and marine and coastal areas (France, 2017).

Bioeconomy in 2018 is defined as:

> "the whole range of activities linked to the production, use, and processing of bioresources. The purpose of bioresources is to provide a sustainable response to the need for food and to part of society's requirements for materials and energy, as well as providing society with ecosystem services." (France, 2017).

OBJECTIVES

The strategy addresses five areas of action:

1. Knowledge
2. The promotion of the demand- and supply-side measures
3. Sustainable production and utilization of bio-based resources
4. Raising public awareness of the bioeconomy and bio-based products
5. Financing mechanisms

PRIORITY AREAS

This strategy aims to promote innovation in primary industries that contribute to sustainable and efficient production and use of bioresources. It focuses on sustainable resource management practices, innovative production systems, and the reclamation of uncultivated land, abandoned farmland, and maritime and aquatic areas to increase biomass resources. The strategy prioritizes the utilization of waste resources from industries and urban areas for energy production, and the development of new value chains from animal by-products. It emphasizes the production of locally sourced biomass into high-value bio-based food, feed, chemicals, materials, and energy. It also focuses on the development of improved biorefineries to ensure state-of-the-art bioenergy conversion and the conversion of biomass resources into pharmaceuticals and foods. Finally, it highlights the exploration of new and alternative food resources from the sea.

ACTIVITIES

The focus is on promoting innovative investments in public and private research and development, encouraging innovative partnerships between the agrifood and industry sectors. This includes infrastructure research, as well as training in biotechnology, agricultural sciences, bioinformatics, and nanotechnology. Public research and development concentrates on photosynthesis, metabolism, and environmental interactions to facilitate adaptation to climate change. The government also recognizes the importance of educating and training the workforce for a future in a bioeconomy.

GOVERNANCE

Governance of the bioeconomy strategy is overseen by a national council composed of stakeholders from industry, non-governmental organizations academic institutions, research institutes, and local, regional, and national decision-makers.

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GERMANY

Germany has established itself as a world leader in bioeconomy policy. In 2010, Germany published the National Research Strategy, "Bioeconomy 2030", and the National Policy Strategy on Bioeconomy in 2013. In the 2020 revised strategy, Germany prioritizes a coherent and sustainable bioeconomy strategy that links industrial and energy policies, agricultural, forestry, and fisheries policies, climate and environmental policies, and research and development policies. The main goal is to make a transition from an economy that is based on fossil fuels to a resource-efficient and sustainable economy that is based on renewable resources (Germany, 2020).

Bioeconomy in 2020 is defined as:

> "the production, exploitation, and use of biological resources, processes, and systems to provide products, processes, and services in all economic sectors within the frame of a sustainable economic system." (Germany, 2020). It is worth noting the close similarity between the German definition and the definition that FAO has adopted.

OBJECTIVES

The strategy aims to achieve six goals:

1. To develop bioeconomy approaches that are aligned with the sustainability agenda
2. To identify and utilize the potential of the bioeconomy within ecological limits
3. To expand and apply biological knowledge in various sectors
4. To sustainably align the resource base of the economy and replace fossil-based raw materials
5. To position Germany as the leading innovation location for the bioeconomy
6. To integrate society and intensify national and international cooperation in the field of bioeconomy

PRIORITY AREAS

1. Ensuring global food security while managing competition for land use
2. Promoting sustainable production and provision of bioresources, with a special focus on agricultural production
3. Ensuring the safety and nutritional value of food
4. Exploring industrial applications of renewable resources
5. Identifying growth markets, innovative technologies, and products
6. Developing efficient processes and value-adding networks
7. Advancing the development of bio-based energy

ACTIVITIES

There is currently no dedicated action plan in place. However, the German Bioeconomy Council has been established as a new advisory body to develop recommendations for specific political measures to implement the strategy.

GOVERNANCE

The Interministerial Working Group and the Bioeconomy Council will ensure that bioeconomy strategy and policy decisions are coherent across administrative levels.
A monitoring system has been in place since 2016.

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IRELAND

The dedicated bioeconomy strategy is a comprehensive plan that defines Ireland's ambition to become a world leader in the bioeconomy sector. The plan incorporates sustainable economic development into the existing economic model to make a transition to a low-carbon, circular economy. The strategy is specifically designed to create new job opportunities, promote rural development, and mitigate climate change (Ireland, 2023).

Bioeconomy in 2023 is defined as:

> "an economy that emphasizes the importance of using an increasing list of renewable biological resources and in some cases what would have hitherto been discarded as residues or waste and putting them to more productive uses. It extends across sectors - from farming and the agrifood businesses, marine and maritime industries, forestry, novel protein production, water and waste management, energy suppliers, and biopharmaceutical products." (Ireland, 2023).

OBJECTIVES

The strategy highlights the importance of bioeconomy in promoting circularity by encouraging innovative practices that promote the reuse and recycling of materials and maximize resource efficiency. It places significant value on converting waste streams into value-added products. The strategy aims to achieve four key objectives:

1. Creating a sustainable economy and society
2. Decarbonizing the economy
3. Generating employment and enhancing competitiveness
4. Promoting regional prosperity, rural development, and employment.

PRIORITY AREAS

The strategy identifies food, forestry, fisheries as the top priority areas for the bioeconomy. The aim is to assist primary producers in the agrifood and marine industries to become a part of the value chain. Biorefining, although a new concept in Ireland, is believed to have the greatest potential for high-value products for export in the form of biomaterials and biochemicals from biomass. The country is also exploring waste management, including household, agricultural, and wastewater, and marine waste. Ireland is also keen on developing BioCities as circular bioeconomy hubs.

ACTIVITIES

Research and innovation are being promoted through increased funding and engagement with private investors, combined with federal support for research centres focused on the bioeconomy. The research aims to achieve the following objectives: optimize circular bio-based products, including animal nutrition, food innovation, health, and sustainability projects; create demonstration projects to integrate and mobilize multi-product, small-scale biorefineries that help farmers become bio-processers; establish a BioCircle to assess available biomass value-chain development, valorization, market-based opportunities, and socio-economic impact; establish the necessary infrastructure for dairy processing of lactic acid into biodegradable plastics, bio-based fertilizer, and biominerals; develop and pilot second-level vocational and higher-education curricula and entrepreneurial programmes.

GOVERNANCE

A high-level implementation group, jointly chaired by the Departments of Agriculture, Food, and Marine; Communications; and Climate Action and Environment, is required to submit annual progress assessments. An associated Bioeconomy Forum comprises industry representatives and other stakeholders in the bioeconomy to provide advice and guidance on implementing the strategy.

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ITALY

The country is committed to integrating bioeconomy and circular economy sectors as part of its economic transition plans. Biorefineries are a vital component of this strategy as they have the potential to revitalize regional economies in an environmentally, economically, and socially sustainable manner (Italy, 2019).

Bioeconomy in 2020 is defined as:

> "the sustainable production of renewable biological resources and the conversion of these resources and waste streams into value-added products such as food, feed, bio-based products, and bioenergy." (Italy, 2019)

OBJECTIVES

The strategy aims to increase Italy's competitiveness through innovation and the promotion of green growth. It seeks to reduce dependence on fossil fuels and non-renewable resources and focuses on rural and coastal development. The strategy works to prevent biodiversity loss and protect ecosystems. It proposes to link production systems for renewable biological resources, promote their competitiveness at producing food, feed, bio-based products, wooden products, and bioenergy. It also emphasizes the transformation and valorization of biowaste streams.

PRIORITY AREAS

The strategy is divided into four macro areas:

1. Promoting policies, standards, labels, and emerging market-based actions and incentives.
2. Launching pilot projects for agrifood, biomass, forestry, and marine and maritime market-based initiatives at the local level.
3. Enhancing the knowledge, protection, and restoration of national biodiversity and ecosystems, ecosystem services, and their resilience to climate change.
4. Promoting awareness, skill upgrading, education, attitude, training, and entrepreneurship across the bioeconomy.

ACTIVITIES

To transition towards a more sustainable future, the strategy focuses on green or biomass-based chemistry. This includes increasing the efficiency and sustainability of the bio-based value chains and generating value from local biodiversity and circular economy approaches. To achieve this, support is given to the agricultural and forest sectors to increase sustainable and resilient primary production. The strategy also focuses on urban issues and the creation of BioCities. It also seeks to improve forest management and increase opportunities for blue growth and jobs. By focusing on the microbiome, the strategy enables better biomass production, improves soils and the health of local communities and environment, and stimulates new sustainable approaches. Better coordination between regional, national, and EU policies and initiatives is essential to realize these goals.

GOVERNANCE

To improve resource management of farming and forestry systems, soil fertility, water quality, photosynthesis capacity, and carbon dioxide sequestration, it is recommended to provide direct funding and tax incentives along with public investments. The development of a sustainable and competitive agrifood sector is also necessary, which can be achieved by improving food safety and security, promoting healthy diets, and exploring alternative food resources. It is important to increase efficiencies in food production, processing, and waste management for biochemicals and biofuels. Infrastructure

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development has also been prioritized, and investors are encouraged to finance the bioeconomy by emphasizing commercialization and increasing demand by implementing standards, labelling, green public procurement, and communications.

To support the implementation of the bioeconomy strategy and ensure coordination among stakeholders, a National Bioeconomy Coordination Group has been established. This group comprises representatives from the Ministries of Agriculture, Food and Forestry; Education, University and Research; and Environment, Land and Sea. They are responsible for overseeing the implementation and monitoring of the bioeconomy throughout the country.

LATVIA

Latvia is becoming a leader in the European Union when it comes to a sustainable bioeconomy. The country focuses on managing natural resources in a way that creates economic opportunities, encourages investment, and promotes sustainable living. The bioeconomy strategy aims to support sectors such as agriculture, fisheries, and forestry, and the production of goods and services that are sustainable and promote the responsible use of natural resources. This includes promoting the use of biomass to create new, eco-friendly value chains, reducing waste and promoting green consumption (Latvia, 2017).

Bioeconomy in 2017 is defined as:

> "a part of national economy where renewable natural resources (plants, animals, micro-organisms, etc.) are used in the production process in a sustainable and well-considered way in order to produce food and fodder, industrial products, and energy." (Latvia, 2017).

OBJECTIVES

The strategy is in line with the 2030 Agenda and adheres to the core principles of the circular economy. The strategy aims to achieve five objectives:

1. Create an attractive business environment for bioentrepreneurship
2. Focus on efficient and sustainable resource management with a results-oriented approach
3. Promote the development of knowledge and innovations in bioeconomy sectors
4. Encourage the manufacturing of produce in bioeconomy
5. Prioritize socially responsible and sustainable development

PRIORITY AREAS

Targets are businesses operating in the primary industries of agriculture, forestry, fisheries, and manufacturing, which have an impact on the food, feed, wood, chemical, pharmaceutical, and textile industries. The primary focus is on environmental protection, exploring untapped marine bioresources, and functional foods, and preventing waste at all stages in the value chain. Biorefining will concentrate on the production of biofuels from cellulose.

ACTIVITIES

The plan places importance on collaboration between the public and private sectors in public-private partnerships. Research institutions are coordinated to focus on agriculture, food, and forestry. The government envisions supporting and co-financing pilot and demonstration projects. Measures related to capacity building, education, commercialization, wood for housing, public buildings, organically certified products, environmentally friendly packaging, and locally produced products are being promoted to increase demand.

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GOVERNANCE

The strategy was elaborated by the Ministry of Agriculture in collaboration with the Latvia University of Life Sciences and Technologies and involved a number of sectoral stakeholders such as scientists, entrepreneurs, and representatives from governmental institutions and non-governmental organizations. It does not identify specific monitoring measures, milestones, or sources of financing.

NETHERLANDS (KINGDOM OF THE)

The bioeconomy strategy focuses on developing a sustainable bioeconomy to address challenges related to climate action, resource dependency, rural development, sustainable food production and job creation. It emphasizes collaboration betwe,nal revitalization as key pillars (The Netherlands, 2018).

Bioeconomy in 2018 is defined as:

> "The production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy." (The Netherlands, 2018).

OBJECTIVES

By tapping into renewable biological resources across various sectors, including agriculture and forestry, the strategy aims to boost economic growth and resilience. With its strong position in green resources and research infrastructure, collaborative efforts between government, businesses, and research institutes are seen as essential for driving innovation and competitiveness in the global bioeconomy.

PRIORITY AREAS

1. Using resources within the planetary boundaries
2. Mitigating climate change
3. Enhancing production for people,
4. Managing resources sustainably
5. Building a stable and predictable legal framework
6. Fostering collaboration in the value chain
7. Undertaking long-term research and setting an innovation agenda
8. Developing a regional strategy for rural development

ACTIVITIES

There is currently no dedicated action plan in place.

GOVERNANCE

Formulated by the Ministry of Economic Affairs and Climate Policy, the strategy lacks an incorporated governance and monitoring framework.

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NORWAY

Norway focuses on the bioeconomy to foster knowledge-intensive industries and ensure competitiveness in the face of global challenges such as climate change, demographic shifts, and resource access. With abundant renewable resources and a strong industrial base, Norway aims to optimize biomass utilization, create sustainable value chains, and drive innovation in a range of sectors (e.g. food, energy, and biotechnology) (Norway, 2016).

Bioeconomy in 2016 is defined as:

> "a concept that includes sustainable, efficient and profitable production, extraction and use of renewable biological resources for food, feed, ingredients, health products, energy, materials, chemicals, paper, textiles and other products. The use of enabling technologies such as biotechnology, nanotechnology and ICT is, in addition to conventional disciplines such as chemistry, key to the development of a modern bioeconomy." (Norway, 2016).

OBJECTIVES

The national bioeconomy initiative aims to enhance value creation and green economic transition through sustainable use of renewable biological resources, and prioritizes measures with national impact on employment, value creation, and emissions reduction.

PRIORITY AREAS

Priorities include:

- fostering collaboration across sectors and industries;
- creating markets for renewable bio-based products;
- ensuring efficient use and profitable processing of renewable biological resources; and
- promoting sustainable production and extraction of these resources.

ACTIVITIES

To achieve cross-cutting cooperation, actions focus on supporting networking activities and clusters, coordinating project support along the value chain, and promoting interdisciplinary collaboration. For creating markets, efforts include providing knowledge on market opportunities, considering standards for bio-based products, and investing in reducing climate gas emissions. To ensure efficient use and profitable processing, initiatives target investments in shared facilities, strengthening research and development funding, and revising regulations to promote recycling and sustainable resource use. Finally, for sustainable production and extraction, strategies involve utilizing biomass potential within sustainable boundaries, enhancing forest management, promoting the exploitation of marine species, and addressing environmental impacts through skills development and regulatory frameworks. Additionally, a joint action plan will be developed by key organizations to implement the strategy's recommendations.

GOVERNANCE

The strategy was developed through extensive stakeholder engagement that included a national conference, six regional meetings, an international seminar with experts, and written submissions from various organizations. It has a timeframe of 10 years, with revision after 5, and an action plan is under preparation.

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NORDIC BIOECONOMY PROGRAMME

The Nordic Council of Ministers – an official body of the intergovernmental cooperative from Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Aland – has promoted bioeconomy development on a regional level (Nordic Council of Ministers, 2018). The timeframe for the strategy has expired.

Bioeconomy in 2018 is defined as:

> it "encompasses the utilization of renewable biological resources and the conversion of these resources (including side streams and waste streams) into value-added products, technology and services". (Nordic Council of Ministers, 2018).

OBJECTIVES

The Nordic strategy follows a sustainable and comprehensive approach that considers environmental, social, and economic factors. It seeks to develop a bioeconomy that creates new industries, generates new job opportunities, and achieves new standards for resource efficiency. The strategy works to enhance the competitiveness of Nordic bio-based and food industries by developing new value chains and guiding the transition of traditional bio-based industries into technologically advanced industries that optimize the production and value creation of biomass. Its goal is to serve the needs of a growing population, mitigate climate change by replacing fossil-based products, and improve the use of natural resources. The strategy includes five sustainability principles: 1. responsible use of shared resources, 2. safe, sufficient, and nutritious foods for everyone, 3. a livable planet, 4. sustainable and fair societies, and 5. mindset and consumer behaviour.

PRIORITY AREAS

The main priority are the primary production industries in rural areas and adding value to biomass products through the promotion of resource efficiency and digitization that uses big data and digital technologies. The strategy offers young people and women opportunities to stay in rural regions by maintaining a degree of self-sufficiency in terms of energy, food and feed, fibre, resiliency, and security. The programme focuses on Nordic region food production, reducing food waste in urban areas, and developing new, sustainable, healthy foods, and pharmaceutical products.

ACTIVITIES

The Nordic bioeconomy strategy provides research and development funds through public-private partnerships and public or private funding. It focuses on mapping the interaction between biological by-products and the development of second and third-generation biofuels. It also aims to establish bio-based start-ups and bridge the gap between pilot projects and commercialization by providing market analysis, subsidies, and tax incentives. By establishing Nordic university degrees and apprenticeships in value chains and new technology programmes, the Nordic bioeconomy strategy also aims to create a sustainable brand that influences consumer behaviour, promotes exports and employment opportunities in rural areas, and attracts young people to the bioeconomy.

GOVERNANCE

The strategy does not make clear how the bioeconomy will be monitored or evaluated.

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PORTUGAL

In 2021 Portugal has released its first national bioeconomy strategy, "The Action Plan for a Sustainable Bioeconomy". The strategy, which is to be completed by 2025, focuses on harnessing biological raw materials for processing and valorization and fostering new value chains across traditional sectors that have been developed collaboratively with representatives from industry, research institutions, and civil society organizations (Portugal, 2021).

Bioeconomy in 2021 is defined as:

> "a segment of the economy that seeks to transform renewable biological resources into value-added resources for subsequent use in the economy and exploitation by the tertiary sector through the creation of new value chains. Bioeconomy encompasses all sectors and systems that depend on biological resources (animals, plants, microorganisms and biomass, including biowaste), its functions and principles, namely the economic and industrial sectors that use biologically based resources and processes to produce food for human and animal consumption, goods and products, energy and services." (Portugal, 2021).

OBJECTIVES

The Action Plan outlines a strategic roadmap to develop a sustainable and circular bioeconomy in Portugal. Emphasizing the utilization of renewable indigenous resources, the plan aims to reduce carbon intensity, ensure food security, preserve biodiversity and manage natural resources sustainably. It seeks to enhance competitiveness and job creation, particularly at the local and regional levels, by promoting innovation and partnerships in bioproducts and bioenergy sectors. Additionally, the plan underscores the importance of consumer awareness and engagement, advocating for transparent value chains and promoting the consumption of biological-based products.

PRIORITY AREAS

Prioritizing sustainable production and optimal utilization of regional biological resources entails fostering robust research, development, and innovation capabilities to transition of traditional sectors towards a bioeconomy. Key focus areas include promoting circular and sustainable bioindustries through innovative value chain optimization and eco-efficient processes. Sector-specific initiatives target textiles, footwear, and natural resin, and harness biomaterials and eco-friendly practices for sustainable growth. Central to these efforts is the drive to heighten societal awareness and foster responsible consumption, which aligns with overarching national environmental and socioeconomic objectives.

ACTIVITIES

To foster regional sustainable bioeconomy agendas across five regions, optimize resource sharing and generate additional income for producers, actions include enhancing sustainable production capacities in agriculture, forestry, and aquatic sectors and improving collaboration among stakeholders. Streamlining material markets, advancing innovative production processes, and integrating digital technologies are also prioritized to make resource management more efficient. Initiatives also emphasize the development of bio-based products to strengthen circularity and follow ecodesign principles. Establishing competence centres and advancing sustainable transport are critical pillars. Incentivizing the use of bio-based resources and evaluating market potentials highlight the county's commitment to transitioning to a circular bioeconomy.

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GOVERNANCE

The Interministerial Commission for Sustainable Bioeconomy and the Coordination Group, led by the Portuguese Environment Agency, ensures intersectoral coordination and monitoring. Representatives from academia, research institutes, non-governmental organizations, and business associations collaborate on other strategies to ensure actions are aligned.

SPAIN

Unlike most EU countries, bioeconomy development in Spain has been more regionally focused than national. Several autonomous regions have established their bioeconomy initiatives. However, in 2018, the Spanish government published the "Spanish Bioeconomy Strategy – 2030 Horizon", a nationwide strategy to transform Spain into a sustainable, resource-efficient, and competitive economy and reduce the consumption of resources and generation of waste by prioritizing knowledge, technologies and partnership with public and private sector (Spain, 2016).

Bioeconomy in 2018 is defined as:

> "the set of economic activities based on products and services, generating economic value, making efficient and sustainable use of resources of biological origin as fundamental elements." (Spain, 2016).

OBJECTIVES

The national strategy focuses on two main elements: climate change and global food security. The primary objective of the strategy is to increase competitiveness and promote economic growth by encouraging the use of innovative technologies and the internationalization of bio-based companies. The goal is to develop a diversified and environmentally friendly sustainable economy that contributes to rural development and strengthens regional cohesion. The five strategic actions outlined in the plan include:

1. Promoting public and private research and investment in innovation
2. Reinforcing social, political, and administrative complexities
3. Promoting competitiveness and development in the marketplace
4. Developing demand for new products
5. Promoting and expanding the bioeconomy

PRIORITY AREAS

The sustainable bioeconomy is driven by a combination of innovations in biosciences and digitization and relies heavily on the competency and economic importance of the agrifood and forestry industries. The strategy promotes more sustainable production and bioeconomy development through new technologies, sustainable intensification practices, and omics technologies. The introduction of new processing, packaging, conservation, and cold chain technologies will help reduce waste throughout the supply chain and improve the nutritional quality of traditional and new functional food. The strategy also promotes marine biotechnology and the development of blue biotechnology and enhances efficiency and sustainability in the use of scarce water resources.

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ACTIVITIES

The plan provides a budget for research and innovation to support innovation programmes in rural development and encourages public and private sector collaboration to improve existing value chains and create new ones. It also promotes the use of clusters and information technology platforms to build bioeconomy infrastructure and improve capacity building and education. Focus is placed on new training and education that meets the needs of the private sector. The plan supports the commercialization of bio-based products to increase the demand for bioeconomy. It also aims to improve the regulatory framework to facilitate bioeconomy development and remove any existing barriers.

GOVERNANCE

A group on bioeconomy monitoring was 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.

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Appendix 3. Mapping of sustainability objectives in national and regional bioeconomy dedicated strategies

FAO has identified 15 major sustainability objectives that drive countries and regions in the development of bioeconomy in national and regional strategies and initiatives.[19] These objectives encompass social, economic, and environmental dimensions, underpinned by governance arrangements. Table A3.1 shows the different shared sustainability objectives and how they are covered by national and regional bioeconomy dedicated strategies.

19 **Gomez San Juan, M. and Bogdanski, A.** 2021. *How to mainstream sustainability and circularity into the bioeconomy? A compendium of bioeconomy good practices and policies.* Rome, FAO. https://www.fao.org/3/cb5798en/cb5798en.pdf

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	✓	✓
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	✓	✓	✓

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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
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	✓	✓	✓	✗

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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	×

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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
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	✓
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	✓	✓	✓	✓

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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	✓	✗	✓

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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
Namibia – The Namibia Sustainable Bioeconomy Strategy	✓	✓	✓	Limited
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	✓	✓	✓	✓

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	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	✗	✓	✓

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	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
Malaysia – National Biotechnology Policy 2.0 – Towards a Bio-Innovative Society (2022 - 2030)	✗	✓	✓	✓
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	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	✗	✓	✓	✓

The global bioeconomy landscape is diverse, reflecting various national and regional interpretations and visions. This study has conducted a global review of national and regional bioeconomy strategies, with a focus on sustainability objectives, definitions, priority areas, activities, and governance mechanisms. It highlights FAO's role in advancing a sustainable bioeconomy within the food and agriculture sectors. The study concludes by identifying gaps and opportunities in global bioeconomy development to guide FAO and its Members in shaping the transition to a sustainable global bioeconomy for food and agriculture.

The concept of bioeconomy is gaining significant global traction, evolving from its early focus on resource substitution and biotechnological innovation to a more comprehensive and cross-cutting model for sustainable development. This perspective underscores its transformative potential, aiming to reshape the existing economic paradigm into one that is economically, environmentally, and socially sustainable. However, bioeconomy is not inherently sustainable. Realizing its potential requires robust governance that ensures alignment with societal goals. Increased biomass demand, central to bioeconomy development, poses challenges such as resource competition and international trade impacts.Without assessing the economic, environment and social sustainability of the bioeconomy, this transition risks exacerbating global inequalities related to resource access, environmental degradation and land rights.

This study was prepared by the Office of Climate Change, Biodiversity and Environment of the Food and Agriculture Organization of the United Nations (FAO), within the framework of its Programme Priority Area bioeconomy for sustainable food and agriculture. The insights gathered aim to guide FAO in shaping the strategic direction of its corporate area of work on bioeconomy, strengthening the role of agrifood systems in driving the transformative potential of the bioeconomy across other sectors.

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