Bioeconomy globalization:

Recent trends and drivers of national programs and policies

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Summary[1]

The bioeconomy holds promise in reducing dependence on fossil fuels, addressing climate change, and promoting resource efficiency, thereby stimulating economic growth, innovation, and improving food security. In 2020, the International Advisory Council on Global Bioeconomy (IACGB) released a comprehensive report that analyzed the progress of bioeconomy policies across the globe up until that year. This study builds on that report, analyzing bioeconomy policy trends between 2020 and 2024. The study aims to contribute valuable insights for policymakers, researchers, and other stakeholders involved in shaping the evolving bioeconomy landscape. In the following, we illuminate some of the most crucial insights that emerge from this analysis.

Recent mega policy trends (2020-2024)

- The bioeconomy is increasingly seen as a key enabler and solution provider to global sustainability challenges across various sectors and dimensions of society.
- Policymakers worldwide recognize the potential of the bioeconomy, and more and more countries and regions around the globe are developing their strategic vision for the bioeconomy in their specific contexts.
- Developing and emerging economy countries are increasingly engaged and, through their bioeconomy strategies, seek to adapt existing technologies (e.g., biorefineries) to local conditions. These efforts aim to address persistent social and economic challenges and usher in immediate change (e.g., job creation).
- International and multilateral cooperation is seen in many bioeconomy strategies as a key building block. Consequently, multilateral organizations have intensified their engagement in, and for, bioeconomy. Under India's lead in 2023, the G20 drew attention to the bioeconomy and, in 2024, Brazil put the bioeconomy even more prominently on the G20 agenda.
- The Food and Agriculture Organization of the UN (FAO) included bioeconomy in its most recent science strategy. Bioeconomy for sustainable food and agriculture is now one of 20 programme priority areas in the FAO Strategic Framework 2022–31. While the actual content of the programme is still emerging, this is a promising initiative.
- The COVID-19 pandemic significantly influenced trends in health-related bioeconomy policy development, a dimension previously received less emphasis. The pandemic also played a role in enhancing supply chain security in bioeconomy-related value chains.

Trends in agendas and contents

- Recent policies and strategies focus on enhancing synergies and minimizing trade-offs among economic, environmental, and social objectives while addressing the Paris climate change goals (SDGs).
- The analyzed governmental documents converge on fundamental objectives to be achieved through bioeconomy expansion; contributing to climate neutrality, food and nutrition security, improved health, economic growth and many other objectives aligned with sustainable development.
- Recent policies and strategies are increasingly emphasizing the pivotal role of the bioeconomy in strategically enhancing global supply chain resilience.

[1] We are grateful for the support of the Centre for Development Research at the University of Bonn and the research project 'Transformations and Sustainability Governance in South American Bioeconomies (SABIO)' at the University of Münster, which is funded by the German Federal Ministry of Food and Agriculture.

- In order to address potential regional biomass supply deficits and facilitate sustainable development, bioeconomy policies promote advanced circularity models that emphasize resource optimization, recycling, use of waste and side streams and sustainable consumption, as well as an increase in biomass productivity (e.g., in agriculture, forestry, and the blue bioeconomy). These initiatives are being driven by biotechnology, precision agriculture, and other innovative manufacturing technologies.
- To achieve these goals, the focus is on reducing transaction costs in production and to grow trade in bio-based resources and products (e.g., through internationally recognized quality standards and sustainability certifications, improved property rights, and enhanced data sharing infrastructures).
- Strategies emphasize the need for a (re-)skilled workforce in the emerging and innovative bioeconomy sectors, including the development of technical and vocational education and training (TVET) programs.
- Specific capacity-building programs are proposed to equip individuals with the necessary knowledge and skills for an effective contribution to the bioeconomy.
- Biosafety (i.e., protecting individuals and the environment from exposure to infectious materials) and biosecurity (i.e., protecting populations of humans, animals, plants, as well as the environment from inadvertent or deliberate release of dangerous biological materials or the misuse of microorganisms, biological materials, and even scientific information) aspects play a rapidly growing role in global bioeconomy policy frameworks.

Growing and changing science focus

- The role of new and traditional knowledge, science, and innovation as a driver of the bioeconomy is extensively emphasized in new strategies.
- Advancements in agricultural biotechnology-driven productivity appear to play a more prominent role in the new strategies of China and the United States, while the strategies within the European Union (EU) place comparatively more emphasis on the development of circular economy models.
- The role of biodiversity is becoming prominent in the framing of a "socio-biodiversity bioeconomy" concept in recent and ongoing policy developments, which emphasizes the protection of the Amazon and the sustainable use of biodiversity and its elements for the provision of economic and social support to local communities.
- Job creation through value addition to primary produce and linking farmers to value chains and new markets, are key objectives in bioeconomy strategies in Eastern Africa.
- Biodiversity and ecosystem services are emphasized in bioeconomy strategies in the Latin America and the Caribbean (LAC) region. Notably, Brazil has developed a new perspective with the "socio-biodiversity bioeconomy" as part of the forest-based bioeconomy and the protection of the Amazon and the provision of economic and social support to local communities. A notable trend observed in the analyzed developments is the integration of artificial intelligence (AI) into all areas of the bioeconomy, with a particular focus on microbiology, enzymology, and synthetic biology leading to the emergence of innovative forms of biotechnology, bioengineering and biomanufacturing.
- These technologies are promoted with a crucial aim to:
    - Advance biotechnology solutions in the health sector;
    - Enable complex circular bio-based economy models;

    - Increase productivity and resource efficiency in biomass production and use;
    - Facilitate the rise of a bio-based industry (e.g., bio-medicine, biomaterials, bio-chemicals, bio-agricultural inputs).
- According to the analyzed government documents, commercializing and the scaling up of innovative bioeconomy products and services present ongoing challenges.

- In bioeconomy policy development, a shift towards local manufacturing in supply chain management is evident. Striking a balance between global collaboration and localized production is crucial for harnessing the Bioeconomy's benefits, fostering a more resilient, sustainable, and innovative manufacturing ecosystem.

Introduction

The bioeconomy can be defined as the "sustainable production, utilization, and conservation of biological resources, encompassing knowledge, science, technology, and innovation, to deliver sustainable solutions across all economic sectors and facilitate a transition to a sustainable economy."[2] The bioeconomy holds great potential for addressing global challenges and driving sustainable development. By utilizing renewable biological resources—such as crops, woody biomass, algae, and marine organisms—and new technologies, the bioeconomy can contribute to reducing dependence on fossil fuels, mitigating climate change, and promoting resource efficiency. Thus, the bioeconomy can contribute significantly to the UN Sustainable Development Goals (SDGs) and the climate change goals enshrined in the Paris Agreement. The bioeconomy can also stimulate knowledge-based economic growth, generate employment opportunities, foster innovation, enhance regional development, and improve food security and health.

However, there are also challenges associated with the bioeconomy. Ensuring sustainability is crucial, as increased demand for biomass resources can put pressure on land, water, and biodiversity, unless the supply side is expanding through sustainable biomass production (e.g., through agro-forestry and other approaches). In addition, the bioeconomy, like any transformative economic policy, should aim for inclusivity and equity to prevent widening social and economic inequalities. Ensuring that all stakeholders, including small-scale primary producers and indigenous communities, benefit from bioeconomy initiatives is essential for a sustainable transition.

Across nations globally, the bioeconomy is increasingly acknowledged as a pivotal strategic instrument in attaining internationally ratified climate objectives and effecting sustainable and inclusive economic transformations. Consequently, since the mid-1990s, an increasing array of political strategies and policies have been committed to fostering and evolving the bioeconomy across diverse spheres and sectors.

In 2020, the IACGB released a comprehensive report that analyzed the progress of bioeconomy policies across the globe up until that year.[3] Since then, bioeconomy policy development has gained further momentum, with major countries and multinational organizations worldwide continuing to take notable steps in

[2] www.iacgb.net: International Advisory Council of the Global Bioeconomy Summit 2018.
(2018). Communiqué: Innovation in the Global Bioeconomy for Sustainable
and Inclusive Transformation and Wellbeing. Available at https://www.biooekonomierat.de/media/pdf/archiv/international-gbs-2018-communique.pdf [26.10.20]

[3] Teitelbaum, L., Boldt, C., & Patermann, C. (2020). Global Bioeconomy Policy Report (IV): A decade of bioeconomy policy development around the world. https://gbs2020.net/wp-content/uploads/2020/11/GBS-2020_Global-Bioeconomy-Policy-Report_IV_web.pdf

driving the development of bioeconomy strategies. This global movement highlights the growing recognition of the bioeconomy's potential to drive sustainable economic growth as well as its ability to address pressing social challenges. In this updated report, we build upon the 2020 Global Bioeconomy Policy Report as a foundation to capture and discuss the most recent and significant policy trends in the bioeconomy policy development over the past four years.

Similar to the 2020 report, this update report utilizes a tentative distinction between **dedicated bioeconomy policies** and **bioeconomy-related policies**. This differentiation highlights a significant trend in policy development, emphasizing the bioeconomy as a holistic and long-term paradigm for sustainable development across diverse sectors and industries **(dedicated bioeconomy policies**). Meanwhile, there are policies that are less paradigmatic, instead focusing more narrowly on various sub-aspects of the bioeconomy without integrating them into overarching strategies (**bioeconomy-related policies**). This dual approach reflects the dynamic evolution of bioeconomy policies, ranging from comprehensive strategies to more specialized, sector-specific, initiatives.

Data

The report is grounded in thorough desk research, encompassing an analysis of bioeconomy-policies worldwide. Significant dedicated bioeconomy policy documents were identified across 10 countries and two regional international organizations. These include influential actors like Brazil, China, the East African Community (EAC), the European Union (EU), and the US. In the annex, we provide an overview of the official dedicated bioeconomy policy documents that we discovered during our research.

Further, we conducted a review of secondary literature (e.g., from international organizations and networks, conference materials, and presentations) to cross-check and complement background information on bioeconomy-related policies. In addition, we benefited from an expert survey with individual members of the IACGB. We invited experts to document relevant bioeconomy-related initiatives in their respective countries and regions since 2020, including bioeconomy programs and strategies that may not have been officially released as governmental policies.

Methods and structure

We utilized the data for a threefold analysis. Firstly, our objective is to offer *a graphical overview* of the global dynamics in bioeconomy policy development. Specifically, we utilize the existing IACGB global mapping data[4] as a baseline to document the evolution of bioeconomy policies between 2020 and 2024. In the analysis, we include both dedicated bioeconomy policy developments and bioeconomy-related policy developments that we found in our data.

Secondly, we conduct an *in-depth analysis* of the dedicated bioeconomy policy documents that have been released by national or sub-national governments—including multinational governmental organizations—since 2020.

For our analysis, we employed an inductive thematic analysis approach to examine the selected documents. The approach involved a bottom-up method, enabling us to derive insights directly from the new strategy documents without imposing a pre-existing analytical framework. By utilizing inductive content analysis, we were able to uncover novel perspectives and gain a deeper understanding of the data, making it a valuable tool for exploring emerging policy trends. Nevertheless, we built on the analytical frameworks used in the 2020 Global Bioeconomy Policy Report to structure the analysis of the new policy documents along the lines of four guiding questions:

- What significant developments in bioeconomy-related policies preceded the current strategy development?

[4] See map at: https://www.iacgb.net/

- What are the overarching societal goals that should be achieved through advancements in the bioeconomy?
- Which key areas of the bioeconomy are prioritized for development in order to achieve these societal goals?
- What policy measures are adopted in these key areas?

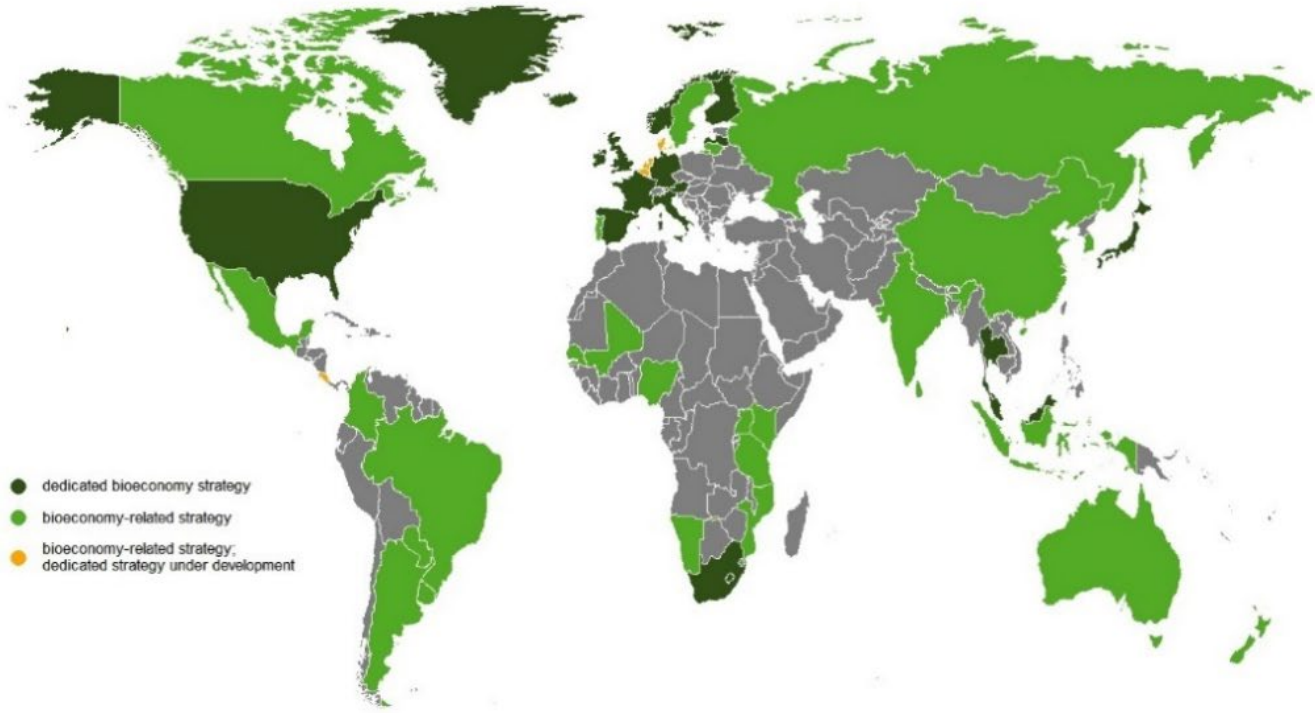
Overall, this analysis sheds light on the shared societal goals, key areas of focus, policy measures, and innovative strategies employed to harness the potential of the bioeconomy in addressing global challenges and fostering sustainable development. Thirdly, in a concluding section, we synthesize the findings from the first two sections to identify and highlight the major trends that are assumed to currently shape the strategic development of bioeconomy policies worldwide. In doing so, we hope to contribute to a deeper understanding of the evolving bioeconomy landscape and provide valuable insights for policymakers, researchers, and stakeholders involved in shaping and implementing bioeconomy and bioeconomy-related strategies at different scales.

Graphical overview: The evolution of bioeconomy policies around the world (2020-2024)

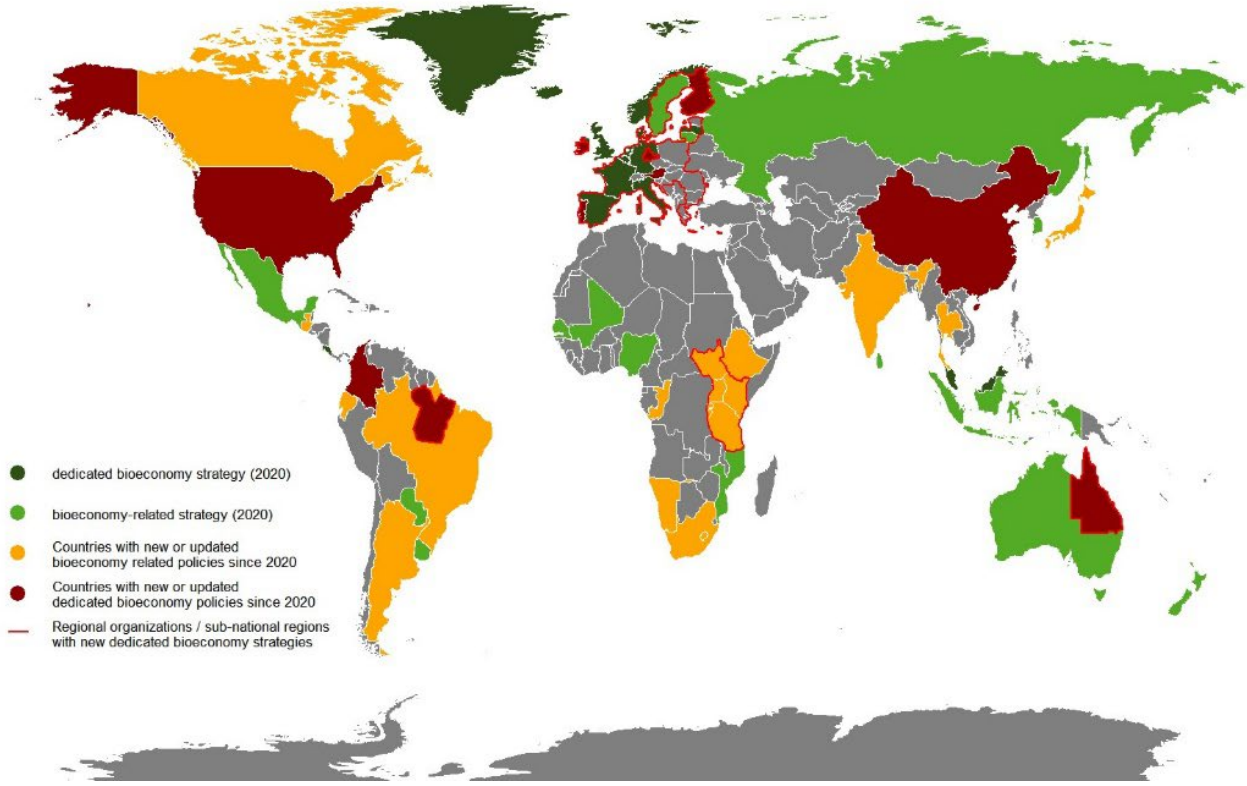
What has been the evolution of bioeconomy policies since 2020? Examining the comparison between the following two maps provides insights into the dynamics of global bioeconomy policy development over the last three years. Map 1 illustrates the global status of bioeconomy policies as reported in the 2020 Global Bioeconomy Policy Report. The information displayed in the map is a reproduction of the data available on the IACGB website under the section titled "Global Bioeconomy."[5]

[5] See: https://www.iacgb.net/GLOBAL

Map 1: Global bioeconomy policies until 2020



Map 1: Global bioeconomy policies until 2020



Map 2 highlights significant advancements in bioeconomy policies since 2020. Countries with notable developments in the establishment of dedicated bioeconomy policies are marked in burgundy red. Particularly noteworthy is the inclusion of China and Colombia among countries with comprehensive and forward-looking strategies for sustainable development across various sectors and industries (dedicated bioeconomy policies). At the sub-national level, important progress is observed in Australia (Queensland), where an existing bioeconomy development plan has been updated and expanded, as well as in Brazil (State of Pará) and Germany (Saxony-Anhalt, Saxony, and Thuringia), where new comprehensive policies are emerging. The red dashed lines surrounding the EU and the East African Community represent significant developments in the bioeconomy by International Regional Organizations.

Further, the map reflects significant developments in bioeconomy-related policies. It is important to note that, regarding the documentation of such policies, we can only present a best effort approach based on the data we could gather through the various means described above. There are certainly significant existing policies that could not be captured by this approach. Therefore, this overview should not be considered exhaustive or complete. Nevertheless, the countries marked in yellow clearly confirm the trend of expanding bioeconomy policies worldwide.

Overall, the comparison between the two maps reveals that, within a relatively short period (three years), a significant number of countries worldwide, including major players, have updated, and progressed their bioeconomy policies (yellow and red). Strikingly, we also observe countries that had no bioeconomy policies in place three years ago but have now begun to develop them.

In-depth analysis: Dedicated bioeconomy policies since 2020

While Map 2 encompasses various advancements in bioeconomy policy and strategy identified through our literature research and input from the IACGB expert network, the subsequent section of the report adopts a more focused approach. It specifically examines official government documents that are updates or renewals of existing dedicated bioeconomy strategies, as well as the introduction of new dedicated strategies (e.g., Colombia). In essence, it involves the countries marked red on Map 2. The section also includes developments within the EAC and the EU. A broader update that includes a comprehensive analysis of all types of new global bioeconomy policies, similar to the 2020 Global Bioeconomy Policy Report, is beyond the scope of this report.

The 2020 Global Bioeconomy Policy Report structured the presentation of dedicated bioeconomy strategies across major geographical regions, which included Africa, the Americas, Asia/Pacific, and Europe. We will maintain this structure in the following section. Links to the official bioeconomy policy documents are provided in the Annex.

Africa

Major developments until 2020: According to the 2020 Global Bioeconomy Policy Report, initiatives in Africa underwent rapid evolution in the years leading up to 2020, with significant developments in various countries. **South Africa** published a dedicated bioeconomy strategy in 2013, focusing on innovations in health, agriculture, industry, environment, and indigenous knowledge. Further, seven eastern African countries—namely **Burundi**, **Ethiopia, Kenya**, **Rwanda**, **South Sudan**, **Tanzania** and

Uganda—collaborated with the Bioresources Innovations Network for Eastern Africa Development (BioInnovate Africa[6]) to create a regional innovation-driven bioeconomy strategy. The strategy, supported by **Sweden**, aimed to promote bioinnovation policies facilitating technology transfer and business development in the region. Additionally, programs like BioInnovation Africa[7] and BiomassWeb[8] have been established to support biodiversity conservation, technology transfer, and business development across countries such as **Cameroon**, **Ethiopia**, **Ghana**, **Kenya, Madagascar**, **Namibia**, **Nigeria** and **South Africa**. Several African nations have also implemented bioenergy, bioprospecting, biotechnology, and ocean economy strategies to drive bioeconomy development. It is also noteworthy that, by end of 2023, 42 African countries had already developed so called "National Pathways" to act on the UN Food Systems Summit recommendations.[9] Main focus areas are policy and regulation, finance and investment, zero hunger, innovation and knowledge, and resilience. These National Pathway documents are relevant for bioeconomy agenda setting in the countries.

Major developments since 2020: In **South Africa**, the health challenge posed by the COVID-19 pandemic resulted in a significant reallocation of research efforts toward addressing the challenge. A major achievement was **South Africa's** ability to rapidly identify new varieties of the COVID-19 virus, and improved methodologies of detecting the virus through sewage (pooled) testing, to narrow down areas to focus individual testing and vaccine treatment. The World Health Organization's mRNA vaccine technology transfer hub has since been established in Cape Town, and has already produced pilot scale mRNA vaccines, contributing to the strategic development of **South Africa's** and Africa's manufacturing ability for vaccines.

A biosecurity hub has been launched that aims to protect the country from new invading sanitary and phytosanitary (SPS) threats and provide information and research services to both the public and private sectors to strengthen biosecurity for **South Africa**. This is particularly relevant in the context of climate change, as SPS can be expected to be confronted with new challenges under ecosystem change in climate change contexts. Further, efforts have been expanded—under the Agricultural Bio-Innovation Partnership Programme—to capacitate small-scale farmers with training and technologies that will enable their ability to move towards a more sustainable (and commercial) level of farming.

A variety of public-private-civil society-developed master plans have been developed to revitalize collective efforts in various industry areas, including sugar, cannabis and hemp, forestry, agriculture, and agro-processing. Specific roles and activities are defined, ranging from regulatory reform to investment, science, and innovation. Finally, an audit of the **South African** bioeconomy has been undertaken and is being prepared for publication.

In 2021, **Namibia** conducted a national bioeconomy stocktaking analysis to establish the policy landscape and focus of the national strategy. The assessment report led to the drafting of the National Bioeconomy Strategy, which was presented to stakeholders in the same year. Subsequently, the draft strategy was submitted to the Minister of Higher Education, Technology, and Innovation in March 2023. Once approved, a Bioeconomy multi-sectoral working group will commence implementation. Led by **Namibia's** National Commission for Research and Technology (NCRST), the

[6] https://bioinnovate-africa.org/

[7] https://www.iucncongress2020.org/sites/www.iucncongress2020.org/files/sessions/uploads/factsheet-bioinnovation-africa-en-2020_

[8] https://www.zef.de/projects/project-details.html?contact=310&project=6&cHash=e83606d0de90d687c0568e06a8f374fc

[9] https://datalab.review.fao.org/datalab/dashboard/food-systems-summit/

country has developed an inter-ministerial process to identify and prioritize national objectives. The comprehensive National Bioeconomy Strategy aims to provide a crosscutting approach to addressing food insecurity, the impacts of climate change, and natural resource scarcity.[10]

In terms of dedicated bioeconomy strategy development, the most notable recent advancement is the establishment of an official regional international bioeconomy strategy update for **East Africa** by the **East African Community (EAC)**. This initiative builds upon the bioeconomy activities mentioned above in the region and represents a significant milestone.

East African Community

The EAC is dedicated to promoting integration, economic development, social progress, and peace and security in the East African region. Recognizing the importance of the bioeconomy, the EAC has prioritized it as a significant area of cooperation. In pursuit of this goal, the EAC formulated a bioeconomy strategy for its member states, which was unveiled in June 2022[11] and officially published in December 2022. The strategy outlines the EAC's vision and objectives for harnessing the potential of the bioeconomy to drive sustainable economic growth and address key challenges in the region.

The new East African bioeconomy strategy recognizes huge potential in the development of a modern bioeconomy to contribute to various critical development goals and outcomes in the region. The overall objective to be pursued through the new bioeconomy strategy is to "achieve economic growth and job creation, making use of the region's bioresources to develop products and services while contributing to an improved environment and climate change mitigation". The EAC bioeconomy strategy focuses on four key bioeconomy development areas that are essential for the region. These areas are:

(I) Food security and sustainable agriculture;
(II) Health and well-being;
(III) Bio-based industrial development; and
(IV) Sustainable energy.

Each of these areas has specific objectives and key results that contribute to the overall goal of the strategy. The strategy aims to address these priorities through targeted actions and interventions to drive sustainable and inclusive bioeconomy growth in East Africa.

Food security and sustainable agriculture

The East African bioeconomy strategy adopts a technology-driven approach to increase food security and to promote the development of a more productive sustainable agriculture. The strategy combines three strategic objectives:

(I) The use of emerging technologies, such as modern bioprocessing, that add more value to primary production and the use of agricultural residues. In doing so, the East African states aim to deliver economic growth and create new value chains and market opportunities for smallholder farmers and small and medium-sized enterprises (SMEs).
(II) The development of efficient protein production systems based on insects or algae etc. that replace resource-intensive animal protein production systems. By embracing these approaches, the East African states aim to meet growing market demands for novel food and feed

[10] Namibia | Sustainable and circular bioeconomy for food systems transformation | Food and Agriculture Organization of the United Nations (fao.org)

[11] See: https://bioeconomy.easteco.org/cgi-sys/suspendedpage.cgi

products at local, regional, and international markets while promoting sustainability and reducing environmental impact.

(III) The utilization of biopesticides, bio-fertilizers, growth-enhancing microorganisms, and biocontrol agents derived from organic and renewable resources. Crop and animal pests and diseases pose significant challenges to agricultural productivity, livelihoods, and nutrition in the region. Climate change further exacerbates these pressures. Imported pesticides and fertilizers are costly for farmers, especially smallholders. Locally made bio-based solutions offer a promising alternative solution to address pest and disease issues sustainably and affordably.

Health and well-being

The East African states depend largely on imported products for diagnosis and treatment of major diseases affecting humans and animals. However, diseases prevalent in the region, such as malaria, are not prioritized by large pharmaceutical companies. Furthermore, the Covid-19 pandemic has exposed the vulnerability of global supply chains and emphasized the necessity for the region to establish its own health solutions. This situation presents a significant opportunity within the bioeconomy framework, particularly by leveraging traditional knowledge in the region to complement existing strategies. In more specific terms, the East African bioeconomy strategy outlines three key result areas to establish a bio-based healthcare sector that promotes the well-being and health of the population:

(I) Strengthening research, development, and innovation capabilities to screen for and manufacture active pharmaceutical ingredients, biopharmaceuticals, diagnostics, and vaccines targeting major diseases in the region.

(II) Utilizing indigenous knowledge and bio-based traditional medicines.

(III) Producing bio-based cosmetics and well-being products based on local and regional biodiversity resources, with the aim of expanding into niche markets at both the regional and international levels.

Bio-based industrial development and sustainable energy

A further objective of the East African bioeconomy strategy related to the development of a bio-based manufacturing industry is to stimulate sustainable economic growth and add value to under-utilized renewable resources in the region. The achievement of this goal is heavily reliant on the advancement of novel and efficient biorefineries. The EAC member states aim to promote the development of a modern bio-industry in four key strategic areas:

(I) The development of a manufacturing base for standardized bio-packaging materials.

(II) The development of enzymes for industrial applications based on the region's microbial biodiversity.

(III) The utilization of locally produced bio-based and renewable (low carbon) building materials in local construction industries.

(IV) The promotion of various textile fibres derived from local agricultural waste materials, with the objective of establishing a thriving and sustainable bio-based fibre industry.

Finally, the strategy emphasizes the importance of expanding the production and utilization of sustainable bioenergy to develop a diverse range of bioenergy products to meet energy needs of households and industries. As an initial step towards achieving this objective, the strategy promotes initiatives in briquette production using waste materials. The aim is to reduce the dependence on inefficient and

health damaging wood fuel. Further steps include the promotion of advanced bio-gas technologies at both the industry and household levels, as well as an increase in the production of biofuels from lignocellulosic materials and algae.

Governance

In the bioeconomy strategy, the EAC sees itself as an international institution that coordinates and orchestrates the development of a regional bioeconomy among its member states. This involves activities such as fostering regional and international partnerships, enhancing research, innovation, and entrepreneurship, promoting regional trade in Africa, catalyzing the development of national bioeconomy strategies, supporting infrastructure improvement for the bioeconomy, and fostering the integration of indigenous and scientific knowledge. Detailed steps are outlined in a Complex Implementation Matrix.

Promotion of national bioeconomy strategies in East Africa

The development of the East African Regional Bioeconomy Strategy was a developed through an open, transparent, and broadly consultative process with a view to include a variety of perspectives and to reflect different contextual realities in the countries in the region. The Strategy has inspired and catalyzed the development of national bioeconomy strategies and subsequent policy development and interventions for sustainable bio-based and inclusive economic growth in the region. Currently **Uganda** and **Ethiopia** are in an advanced stage of developing bioeconomy strategies inspired by the Regional Bioeconomy Strategy.

Americas

Latin America and the Caribbean (LAC) region

Major developments until 2020: The 2020 Global Bioeconomy Policy Report highlighted the increasing recognition of the bioeconomy in **Latin America** and the **Caribbean (LAC)** region. However, the adoption of dedicated national bioeconomy strategies has been relatively slow in the region, despite the development of several bioeconomy-related policy strategies.[12] Countries such as **Argentina**, **Brazil**, **Colombia**, **Ecuador**, **Guatemala**, **Puerto Rico** and **Uruguay** have been actively working on formulating bioeconomy policies over the years. However, **Costa Rica** stood as the only country so far to have published a dedicated national bioeconomy strategy, which was released in August 2020.[13] The strategies in the region primarily aim to harness the abundant natural resources for sustainable development and green growth. Sustainable use of biodiversity and valorization of waste biomass and side streams are priority areas in most bioeconomy initiatives. **LAC** countries have achieved notable progress in various bioeconomy sectors, including bioenergy, agricultural biotechnology, low-carbon agriculture, biodiversity utilization, ecosystem services, and health (both human and animal). **Brazil** and **Argentina** have emerged as leaders in bioenergy production and the utilization of genetically modified crops, while the state of Amazonas in **Brazil** has made remarkable strides in advancing a tropical forestry-based bioeconomy as well as the state of **Pará** on Socio-biodiversity Bioeconomy (see section below on Pará).

[12] During the period under consideration, a main reason for the "slow" development of dedicated bioeconomy strategies was COVID-19. Latin America was the development region hardest hit by COVID-19. Many countries shifted their priorities in favour of short-term concerns at the expense of developing long-term development views, such as the elaboration of National Bioeconomy Strategies.

[13] https://www.conagebio.go.cr/sites/default/files/2022-11/Estrategia%20Nacional%20Bioeconomi%CC%81a%20CR_0.pdf

Major developments since 2020: As the documents shown below[14] demonstrate, a number of important recent policies related to the bioeconomy below the threshold of dedicated policy development exist in **Argentina and Brazil**. Further, **Brazil** is currently in the phase of developing a dedicated holistic national bioeconomy strategy.

Bioeconomy is on the agenda of two regional international organizations, **The Inter-American Institute for Cooperation on Agriculture (IICA),** and **The UN Economic Commission for Latin America and the Caribbean (UN-ECLAC). UN-ECLAC** considers the bioeconomy to be one of the engines of sustainable and inclusive growth due to its role in promoting a deep transformation of the countries' productive structures. In support of this, **UN-ECLAC** highlights its contribution to the diversification of economic activities, increasing value addition, the incorporation of modern knowledge in biological sciences and related technologies, as well as the enhancement of traditional knowledge. Indeed, bioeconomy—focussing on sustainable agriculture, sustainable use of biodiversity, and bio-industrialization—has been identified as one of the strategic areas for the transformation of the development model in **Latin America** and the **Caribbean.**[15]

Recognizing the importance of measuring the economic value of the bioeconomy, **UN-ECLAC** has developed a methodology to transform the accounting frameworks of national accounts (supply and utilization tables) into databases that can be used to construct Satellite Bioeconomy Accounts.[16] Calculations have been carried out for 13 Latin American countries.[17] On average, bioeconomic products in the region

[14] *Argentina*: Ministry of Science, Technology and Innovation. 2018 Argentine Regions Bioeconomy Program (BAR). (online). Accessed May 8, 2023. Available at: https://www.argentina.gob.ar/ciencia/financiamiento/programa-bioeconomia-regiones-argentinas-bar ; Ministry of Economy. 2022. Bioeconomy. (online) Government of Argentina. Consulted May 8, 2023. Available at: https://www.argentina.gob.ar/agricultura/bioeconomia , Ministry of Economy. 2019th. Action Plan for the Biomaterials and Bioproducts Sector. Resolution 33/2019. (online). Accessed May 8, 2023. Available at: https://www.argentina.gob.ar/agricultura/alimentos-y-bioeconomia/alimentos-y-bebidas/biomateriales/plan-de-accion-para-el-sector , Ministry of Economy. 2019b. The Ministry of Agriculture, Livestock and Fisheries launches an Action Plan to promote Bio-inputs for agricultural use. (online). Accessed May 8, 2023. Available at: https://www.argentina.gob.ar/noticias/el-ministerio-de-agricultura-ganaderia-y-pesca-lanza-un-plan-de-accion-para-promover-los#:~:text=El%20Ministerio%20de%20Agricultura%2C%20Ganader%C3%ADa%20y%20Pesca%20estableci%C3%B3%20un%20%22Plan,disponibles%20para%20las%20actividades%20agropecuarias. , Ministry of Economy. 2021. Argentine Bioproduct Seal. (online). Ministry of Economy in Argentina. Consulted May 8, 2023. Available at: https://www.argentina.gob.ar/agricultura/sello-bioproducto-argentino

Brazil: BRAZILIAN BIOECONOMY PROGRAM – SOCIOBIODIVERSITY in charge of MAPA that seeks to strengthen and coordinate bioeconomy actions in the country's national market, through five axes: The Program is organized under five thematic axes: 1) Productive structure of supply chains extraction (Pro-extraction); 2) Medicinal and aromatic herbs, seasonings, oils and special teas from Brazil; 3) Renewable energies for family farming; 4) Recognition of traditional agricultural systems; and 5) Routes of socio-biodiversity https://www.in.gov.br/en/web/dou/-/portaria-n-121-de-18-de-junho-de-2019-164325642; ACTION PLAN ON SCIENCE, TECHNOLOGY AND INNOVATION IN BIOECONOMY by MCTIC that aims to produce and apply scientific and technological knowledge to promote social, economic and environmental benefits, filling essential knowledge gaps, fostering innovation and providing conditions for the strategic insertion of the Brazilian bioeconomy in the global scenario. https://repositorio.mctic.gov.br/bitstream/mctic/4355/1/2018_plano_acao_ciencia_tecnologia_inovacao_bioeconomia.pdf ; NATIONAL BIOINPUTS PROGRAM https://www.in.gov.br/en/web/dou/-/decreto-n-10.375-de-26-de-maio-de-2020-258706480; For recent study on Brazil see also: https://agro.fgv.br/node/1718

[15] https://repositorio.cepal.org/server/api/core/bitstreams/d3031a92-23f6-42b3-9c2a-2dda44f4fbf6/content

[16] https://repositorio.cepal.org/server/api/core/bitstreams/19f09d4d-6bbc-43a7-9dec-579c7b7583f0/content

[17] The countries are Argentina, Brazil, Chile, Colombia, Costa Rica, the Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Peru.

represent 17.2% of the gross value of production, 12.5% of imports, 24.5% of taxes on products, 18.6% of intermediate consumption, 28.6% of exports, and 24.9% of final consumption. Shares in total value-added range from 5.4% (Panama) to 24.9% (Nicaragua).

IICA plays a significant role in bioeconomy development in the region and has recently prepared a technical note on this subject.[18] The **IICA** has also played a major role in the development of other pathways of the bioeconomy, such as biofuels or applications of biotechnology in agriculture. In both areas, it has supported **LAC** countries in the formulation and implementation of regulations and regulatory frameworks. There are currently nine countries that already have regulations in operation in biotechnology, with an additional four in the formulation process in liquid biofuels there are nine countries in implementation and two in formulation.

In the past two years, bio-inputs for sustainable agriculture have emerged as one of the most rapidly advancing topics within the bioeconomy. At least nine countries in the region have achieved tangible advancements, with several having already launched and begun implementing strategies and policies. In addition to efforts at the country level, there are aspirations to formulate bioeconomy strategies or initiatives at the regional and international levels. For instance, the **Amazon countries** have engaged in numerous dialogues focused on how the bioeconomy can serve as a strategy for sustainable development. While there has been progress, there is still a considerable distance to cover. This was a central theme at the Summit of Amazonian Presidents in Belém, **Brazil**, at the beginning of August 2023. Similar discussions about the bioeconomy as a regional strategy have taken place within **Mercosur.**[19]

Indeed, there is a growing emphasis on the protection of the Amazon and the provision of economic and social support to local communities, framed as a "sociobiodiversity bioeconomy." This perspective is highlighted in **Brazil**, where the Secretariat of Bioeconomy, under the Ministry of Environment, focuses on forest-based bioeconomy, distinguishing it from biotechnology or biomaterial focused approaches. Similar approaches are observed in **Colombia** and **Ecuador**, where forest-based strategies are presented as more sustainable and socially inclusive. **Ecuador** has taken steps toward a National Strategy, including a "Pacto Nacional por la Bioeconomía Sostenible"[20] and a recently published "Libro Blanco de Economiá Circiular."[21]

In **Brazil**, bioeconomy, decarbonization and transition, and energy security constitute one of the six missions of the Neo-industrialization Plan of Action 2024-2026 (Plano de Ação para a Neoindustrialização 2024-2026). The specific objectives of the mission are: (i) Expand the productive capacity of **Brazilian** industry through the production and adoption of inputs, including critical materials and minerals, low-carbon technologies and processes, and energy efficiency; (ii) Strengthen production chains based on the circular economy and sustainable and innovative use of biodiversity, develop bioeconomy industries and promote the valorization of forests in sustainable forest manage-

[18] IICA et al. 2024. Informe de Situación y Perspectivas de la Bioeconomía en América Latina y el Caribe 2023 - 2024; Informe de situación y perspectivas de la bioeconomía en América Latina y el Caribe/Instituto Interamericano de Cooperación para la Agricultura; San José, C.R.: IICA, 2023

[19] Bisang, R. y Regúnaga M. (2022). La bioeconomía como estrategia para fortalecer la integración del Mercosur. San José, IICA, 2022. https://repositorio.iica.int/bitstream/handle/11324/21344/BCO22118631e.pdf?sequence=1&isAllowed=y; See also: Concertação pela Amazônia (2021), Uma agenda pelo desenvolvimento da Amazonia. Grupo de Trabalho Bioeconomia da iniciativa, Uma agenda pelo desenvolvimento da amazonia (access 22/01/2022)

[20] https://www.produccion.gob.ec/se-suscribio-el-pacto-nacional-por-la-bioeconomia-sotenible-para-el-uso-eficiente-de-los-recursos-naturales/

[21] https://www.produccion.gob.ec/wp-content/uploads/2021/05/resumen-Libro-Blanco_WEB_FINAL_A4-1.pdf

ment; (iii) Strengthen industrial chains for energy transition, with a view to autonomy, energy efficiency and diversification of the Brazilian energy matrix; (iv) Develop strategic technologies for decarbonization, energy transition, and bioeconomy, catalyzing intrinsic advantages of the country with a view to the strengthen the Brazilian industry in domestic and international markets; and (v) Guarantee energy security, stimulating low-cost and low-carbon oil and gas production. The aspirational goal for 2033 is to promote green industry, reducing CO_2 emissions by 30% by adding value to the industry, expanding the participation of biofuels by 50% within the transport energy matrix, and increasing the technological use and sustainable biodiversity of the industry by 1% per year. The mission identifies bioenergy, biocosmetics, and equipment for the generation of renewable energy niche areas for the development of industry.

In **Colombia**, the bioeconomy is included within Agroindustry and Food Security, one of the four national strategic areas of the National Reindustrialization Policy. The strategic area involves the development of the bioeconomy for sustainable and regenerative production in agriculture and cattle raising; promotion of the local commercialization and industrialization of bio-inputs and bioproducts derived from biotechnology for agroindustry; the use of new technologies and access to capital goods to optimize agricultural production (precision agriculture) and ecological restoration; and promoting modernization and productive inclusion in agriculture. Moreover, bioeconomy-relevant elements are also included in the strategic areas of energy transition (e.g., decarbonization and reducing the economic dependency on fossil and mineral resources) and reindustrialization in the health sector (e.g., biotechnology medicines).

Argentina's recent bioeconomy developments include institutional developments, such as the creation of the Secretary of Food and Bioeconomy in 2016 within the Ministry of Agriculture, Livestock and Fisheries, and subsequent entities. The 2022 Bioeconomy Action Plan focuses on sustainable development, promoting innovative practices, and facilitating international market access. In 2023, the "Biodesarrollar program" offered financial aid for biotechnology projects. Over the past five years, training initiatives provided by the Ministry of Agriculture together with the Ministry of Science, Technology and Innovation and the Grain Exchange (Bolsa de Cereales) engaged over 10,000 students and networks. Bioeconomy is also included in new industrialization strategies that were launched by **Brazil** and **Colombia** in early 2024. The Latin American Bioeconomy Network, which was formed in 2023, includes links with **Argentina**. During 2022 and 2023 there have been two major changes in Argentina: First in 2022, it was decided to include the Ministry of Agriculture as part of the Ministry of Economy, therefore becoming a Secretary of Agriculture, Livestock and Fisheries. The new administration has meanwhile changed this to the Secretary of Bioeconomy (no more Secretary of Agriculture, Livestock and Fisheries). The new Secretary of Bioeconomy includes an Undersecretary of Bioeconomy. The holistic approach utilized in the country—encompassing agriculture, technology, and international collaboration—has positioned Argentina among the bioeconomic leaders.

Colombia

Since 2020, Colombia has stood out as the country among the LAC countries that has recently developed a dedicated national bioeconomy strategy. After Costa Rica, it is now the second Latin American country to publish a dedicated bioeconomy strategy. Colombia recognizes the tremendous potential of developing its bioeconomy to advance broader societal objectives, with a particular emphasis on sustainable growth that is inclusive, productive, and equitable.

Colombia is committed to implementing a comprehensive bioeconomy strategy that aligns with, and is guided by, the SDGs. Significantly, the development of the bioeconomy

began in 2015 with the program known as Colombia Bio,[22] which remains active today. Colombia Bio is a strategic program of national significance, launched with the objective of promoting knowledge, appreciation, conservation, and sustainable use of biodiversity. The primary aim of Colombia Bio is to lay the foundations for the bioeconomy in Colombian regions by leveraging science, technology, and innovation. Drawing on earlier bioeconomy-related policies (basado en Conpes 3934 Politica de Crecimiento Verde y OCDE), Colombia defines the bioeconomy as an economy that efficiently and sustainably manages biodiversity and biomass to generate new products and processes with added value, based on knowledge and innovation. In its new 2020 strategy document,[23] Colombia—endowed with exceptionally rich biodiversity and highly conducive conditions for biomass production—recognizes the potential of developing a vibrant bioeconomy.

Colombia's 2020 bioeconomy strategy is centred around the establishment of five key strategic areas, each accompanied by a set of measures aimed at their achievement. The strategic areas include:

(i) Biodiversity and ecosystem services
(ii) Biointelligent Colombia
(iii) Productive and sustainable agriculture
(iv) Biomass and green chemistry
(v) Health and well-being

Biodiversity and ecosystem services

The Colombian government places great emphasis on harnessing the abundant biodiversity in both continental and oceanic ecosystems to achieve sustainable economic growth. To attain this goal, the strategy outlines three key focus areas. First, it involves the development of a comprehensive national plan for bioprospecting, which includes the protection of traditional and local knowledge. Second, it aims at enhancing the capabilities for sustainable commercial utilization of continental and oceanic biodiversity, along with their valuable ecosystem services. Lastly, it promotes the conservation and restoration of resilient continental and oceanic ecosystems to foster sustainable development.

Biointelligent Colombia

Colombia aims to transform itself into a biosmart nation. The government has implemented a high-tech approach that involves sequencing of Colombian species' genomes. Moreover, it plans to utilize this knowledge to develop health monitoring tools, leveraging a deeper understanding of the Colombian Human Genome. The strategy also integrates bioengineering and bioinformatics, with a specific focus on the advancement of essential drugs, biotechnological products, biosimilars, and phytotherapeutics. Key components include establishing a national centre for biointelligent information and development of human talent capable of driving a Biointelligent Colombia.

Productive and Sustainable Agriculture

According to Colombia's new bioeconomy strategy, the country is being confronted with a major challenge: transitioning to a productive and sustainable agriculture sector that fosters social cohesion. To tackle the challenge, the Colombian government has deployed four substrategies:

(i) Strengthen biotechnology to develop a more sustainable, productive, and climate-resilient agri-food system.
(ii) Invest in smart, digital, and precision agriculture to optimize agricultural practices.
(iii) Highlight the crucial role of agroforestry, agroecology, and agrobiodiversity in promoting sustainable agriculture and preserving natural resources.

[22] https://minciencias.gov.co/portafolio/colombia-bio

[23] https://minciencias.gov.co/sites/default/files/upload/paginas/bioeconomia_para_un_crecimiento_sostenible-qm_print.pdf

(iv) Enhance capacities in the application of Good Agricultural Practices to ensure that agricultural activities align with sustainable development principles.

Biomass and green chemistry

The Colombian Bioeconomy Strategy also promotes sustainable biomass production and green chemistry. The aim is to achieve sustainable transportation by using bioenergy (e.g., sustainable biofuels. Additionally, it seeks to develop bio-based products derived from biorefineries and develop biological catalysts, specifically enzymatic processes, to facilitate the conversion of biomass and accelerate the advancement of green chemistry. Furthermore, it emphasizes technological development and innovation in scaling up bio-industrial processes. Building institutional capacities and human talent training are, according to the strategy document, crucial components for effectively utilizing and valorizing biomass for green chemistry and energy purposes.

Health and well-being

Finally, the Colombian government's bioeconomy strategy leverages advanced technologies to improve health and well-being. It includes personalized and translational medicine for disease prevention, diagnosis, and treatment, as well as promoting regenerative medicine and addressing mental health. Precision nutrition approaches are also being implemented to foster a healthy population. Institutional capacity and talent development in health biotechnology are being strengthened to support these initiatives.

Political and Legal Framework

Colombia's bioeconomy strategy encompasses the entire country but also considers the individual regions with their respective comparative advantages for the implementation of the strategy. The strategy provides a comprehensive governance approach that integrates the development of the bioeconomy as a strategic goal across various ministries. Colombia's strategy recognizes the need for a significant adjustment of the legal framework to develop a dynamic bioeconomy. It includes the development of new standards and ensuring property rights to reduce transaction costs in emerging bioeconomic markets. It also involves regulatory measures to align the bioeconomy with ecological and social objectives. Additional measures to strengthen the Colombian bioeconomy include promoting exports and expanding international cooperation. Enhancing the research sector and improved education for the Colombian population, particularly in high-tech industries, complete the package of measures.

North America

Major developments until 2020: In 2012, the **US** emerged with a comprehensive bioeconomy strategy that prioritized five strategic objectives to maximize economic benefit across sectors from bio-related discoveries: strategic research and development, translation of discoveries to commercialization, reduction of regulatory bureaucracy, workforce development, and incentives for public-private partnerships Further, follow on reports from specific federal agencies detailed the importance and prevalence of biomass.[24] In contrast, **Canada** has pursued an industry-driven national strategy, primarily emphasizing access to biomass in agriculture for its bioeconomy development. At the time of the publication of the 2020 Global Bioeconomy Policy Report, there were visible efforts within the White House and proposed legislation to strengthen the bioeconomy in the US. However, a replacement of

[24] Dept of Energy 2016 Billion Ton report https://www.energy.gov/eere/bioenergy/2016-billion-ton-report) as well as the economic impacts of biobased industry (USDA 2014 – present dayhttps://www.biopreferred.gov/BioPreferred/faces/pages/EconomicAnalysisReports.xhtml

the 2012 National Bioeconomy Blueprint was still pending.

Major developments since 2020: Although efforts began years before (during the Trump Administration),[25] the recent publication of a renewed bioeconomy strategy in the US in September 2022 is the most significant development in North America.

United States

On September 12, 2022, President Biden signed an Executive Order (EO) titled "Advance Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy."[26] The purpose of the Executive Order is to address the political fragmentation of the past decade by explicitly framing the promotion of bioeconomy development as a "whole of government" task. In essence, this initiative comprises commitments towards biotech research, development of the biotech workforce, enhanced support for biomanufacturing, and the implementation of streamlined regulations aimed at lowering obstacles and reducing transaction costs, among other key aspirations. The EO underscores the capacity of both biotechnology and biomanufacturing to contribute significantly to meeting societal health objectives, addressing climate change, advancing energy solutions, fostering innovation in food and agriculture, strengthening supply chains, and bolstering national and economic security. In order to achieve these goals, the EO defines the following objectives:

(i) Research and Development (R&D) Investment: Strengthen and coordinate federal investment in key R&D areas of biotechnology.
(ii) Biological Data Ecosystem: Foster a secure and responsible biological data ecosystem that drives innovation in biotechnology.
(iii) Biomanufacturing Capacity: Improve and expand domestic biomanufacturing production capacity, emphasizing piloting and prototyping for practical applications.
(iv) Sustainable Practices: Promote sustainable biomass production and provide climate-smart incentives for American agricultural and forest stakeholders.
(v) Market Expansion: Expand market opportunities for bioenergy and biobased products and services.
(vi) Workforce Development: Train and support a diverse and skilled workforce, nurturing the next generation of leaders in biotechnology.
(vii) Regulatory Clarity: Clarify and streamline regulations to support the safe use of biotechnology products, following a science- and risk-based approach.
(viii) Biological Risk Management: Elevate biological risk management in biotechnology R&D, including investments in biosafety and biosecurity.
(ix) Standards and Metrics: Promote standards and metrics for the bioeconomy to inform policy, decision-making, and ensure equitable and ethical development.
(x) Security Measures: Adopt a proactive approach to secure and protect the US bioeconomy, addressing threats and risks, including digital intrusion efforts by foreign adversaries.
(xi) International Collaboration: Engage with the international community to enhance cooperation in biotechnology R&D, aligning with US principles and promoting safe and secure practice.

[25] https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/10/Summary-of-White-House-Summit-on-Americas-Bioeconomy-October-2019.pdf
[26] https://www.whitehouse.gov/briefing-room/presidential-actions/2022/09/12/executive-order-on-advancing-biotechnology-and-biomanufacturing-innovation-for-a-sustainable-safe-and-secure-american-bioeconomy/

In summary, these policies reflect a comprehensive strategy to foster innovation, sustainability, and security in the field of biotechnology and biomanufacturing. The EO defines biotechnology as technology that "applies to or is enabled by life sciences innovation or product development." Biomanufacturing is defined "as the use of biological systems to develop products, tools, and processes at commercial scale." The EO mandates a large number of different US government institutions to develop reports, assessments, and targets on how the defined biotechnology and biomanufacturing policies can be implemented. A useful summary of the new US strategy, "White House Initiative to Advance the Bioeconomy, E.O. 14081: In Brief," was provided last year by the Congressional Research Service.[27] It describes each of the deliverables, their deadlines, and entities responsible for them in an organized fashion.

As of January 2024, several but not all of the anticipated deliverables and reports mandated under the EO have been released and include:

- Report to the President: Biomanufacturing to Advance the Bioeconomy (December 2022)
- Bioeconomy Lexicon (December 2022)
- Developing a National Measure of the Economic Contributions of the Bioeconomy (March 2023)
- Bold Goals for US Biotechnology and Biomanufacturing (March 2023)
- Ambiguities, Gaps, Uncertainties in Regulation of Biotechnology (March 2023)
- Building the Bioworkforce of the Future (June 2023)
- The Coordinated Framework for Regulation of Biotechnology: Plain Language Information on the Biotechnology Regulatory System (November 2023)
- Vision, Needs, and Proposed Actions for Data for the Bioeconomy Initiative (December 2023)

One of these, "Bold Goals for US Biotechnology and Biomanufacturing: Harnessing Research and Development to Further Societal Goals," lays out specific and quantitative aspirations that are believed to be achievable through strategic investments in research and development.[28] Perhaps interestingly, whereas the EO does not mention the terms "circular" or "circularity," the Bold Goals research and development report specifies key aspirations that relate directly to circularity. The document is the result of a collaborative effort by four different departments and the National Science Foundation, with each entity contributing an individual section to the comprehensive renewed US research and development strategy. Given the ambitious nature of this document, our summary will concentrate on its key points and objectives, although the available reports on bioeconomy lexicon, measurement, regulatory clarity, workforce, and data all provide relevant details relating to the key elements of the comprehensive strategy.

Bold Goals for US Biotechnology and Biomanufacturing

This report by the US government outlines five primary societal goals for which technological advancements in the bioeconomy are deemed crucial. These goals address climate change, innovation in food and agriculture, supply chain resilience, human health, and cross-cutting advances. In addition, the strategy identifies 21 key development themes within the bioeconomy, each aligned with one of the societal goals. Moreover, the document specifies two to five short- and long-term sub-goals for each key objective and outlines various research and development (R&D) requirements considered necessary to achieve the goals.

[27] See: https://crsreports.congress.gov/product/pdf/R/R47274

[28] https://www.whitehouse.gov/wp-content/uploads/2023/03/Bold-Goals-for-U.S.-Biotechnology-and-Biomanufacturing-Harnessing-Research-and-Development-To-Further-Societal-Goals-FINAL.pdf

Climate change solutions

Four key development themes and corresponding sub-goals of the renewed US bioeconomy strategy focus on creating innovative climate change solutions:

(i) Enhancing the production of carbon-neutral transportation and stationary fuels by increasing the utilization of biomass and waste to produce liquid fuels. This is particularly important for sectors such as aviation, maritime, rail, and off-road transportation that cannot be easily electrified or powered by hydrogen solutions.

(ii) Ensuring significant progress in decoupling industrial production from fossil fuels by the development of bio-based chemicals and materials with lower carbon intensity. It also emphasizes the importance of conversion of bio-based feedstocks into recyclable polymers within a cost-effective circular economy model.

(iii) Expanding the production of climate-focused agricultural systems and plants. This includes developing improved tools for measuring robust feedstock production systems, engineering more drought-tolerant feedstocks that can thrive on underutilized land, and designing food protein production systems based on microbial protein production from waste feedstocks.

(iv) Prioritizing increased carbon dioxide removal by exploring biotechnology solutions. Examples include techniques such as root microbiome design and utilizing biomass from purpose-grown crops or waste materials while ensuring the durable storage of biomass carbon in long-lasting solid carbon materials or suitable geological formations.

Innovations in the food and agriculture sector

Three key objectives and their corresponding sub-goals revolve around driving innovation in the food and agriculture sector:

(i) The first objective is dedicated to enhancing sustainability and resource conservation, while simultaneously increasing agricultural productivity. To achieve this, the strategy outlines five steps to avoid trade-offs between sustainability and productivity in agricultural production:
   - Increasing total factor agricultural productivity, while ensuring efficient use of natural resources and promoting conservation practices.
   - Advancing climate-smart feedstock production for the utilization of biofuels.
   - Developing technologies to reduce nitrogen emissions from agriculture.
   - Mitigating methane emissions through initiatives such as biogas production.
   - Promoting the development and commercialization of new technologies to minimize food loss and waste.

(ii) The second objective aims to enhance food nutrition, quality, and consumer choice. The strategy emphasizes three bioeconomy advancements: new food and feed sources, improved nutrient density in plants and animals, and better screening tools for food safety.

(iii) The third objective is to enhance the protection of plants and animals from environmental stressors. Key measures include bolstering pest and pathogen detection and mitigation capabilities and strengthening resilience against both biotic and abiotic stressors.

Supply chain resilience

The next three key themes and related subgoals focus on enhancing agriculture supply chain resilience. Supply chain resilience refers to the ability of a supply chain to withstand and recover from disruptions while maintaining its essential functions. It involves adapting to unexpected events, such as natural disasters, geopolitical instability, pandemics, supplier bankruptcies, and transportation disruptions. The new strategy recognizes the bioeconomy's threefold objectives in mitigating these risks, particularly in the context of supply chain disruptions in the pharmaceutical industry due to the COVID-19 pandemic and increased geopolitical tensions:

(i) The first objective is to enhance economic security by utilizing biotechnologies and biomanufacturing to develop alternative supply chain pathways, particularly for critical drugs and sectors facing supply chain bottlenecks. It includes reshoring chemical manufacturing processes.
(ii) The second objective is to boost biomanufacturing innovation by improving predictive capabilities to identify supply chain weaknesses and enabling real-time adjustments through platform technologies.
(iii) The third objective is to strengthen standards and data infrastructure to support biotechnology and biomanufacturing commercialization, including the development of integrated biological data technologies and the promotion of international standards for emerging biotechnologies and biomanufacturing.

Health improvements

While supply chain resilience is a new theme in bioeconomy strategy development, the significant role of the bioeconomy in improving health outcomes has been extensively explored. The new US bioeconomy strategy encompasses five key objectives to drive health improvements:

(i) Developing accessible health monitoring tools by identifying next-generation bio-indicators and creating an affordable integrated diagnostic kit.
(ii) Advancing precision multi-omic medicine by collecting diverse population data and enabling personal multi-ome analysis.
(iii) Enhancing the biomanufacturing of cell-based therapies for increased efficacy and scalability.
(iv) Leveraging AI-driven bioproduction to enhance manufacturing speed and diversity.
(v) Advancing gene editing techniques for improved efficiency and scalability.

Cross-cutting goals

Finally, the new strategy document outlines six cross-cutting key objectives for advancing basic bioeconomic research:

- The first objective is to significantly enhance the ability to sequence genes from diverse microbial species and understand their functions, serving as a prerequisite for developing new products and processes with applications in disease diagnosis, resilient crop development, clean energy generation, and more.
- The second and third objectives concern significant advancements in the reliable design of biological systems with specific functions, which is also referred to as the "holy grail" of engineering biology (p.23).
- The fourth objective involves enhancing quality control of bio-based production processes when scaled up for commercial mass production, beyond laboratory conditions.
- Fifth, the goal is to reproducibly manufacture devices that integrate living and non-living components such as organ-chip or human-robotic interface.

- Lastly, the strategy emphasizes that the societal impact of the bioeconomy relies on public acceptance and adoption of these innovations, necessitating scientific progress in stakeholder engagement and public involvement.

Overall, this research and development-oriented section of the new US bioeconomy strategy, once again, emphasizes the critical role that the US government places on innovation and technological advancements as the central driving forces of the bioeconomy. Leveraging the synergies of biotechnology, chemistry, and artificial intelligence, aims are to advance bioengineering and drive tangible innovations across the areas of climate mitigation, agriculture, supply chain resilience, and health sectors. At the same time, the US strategy emphasizes the implementation of tangible measures aimed at mitigating biological risks linked to the progress of biotechnology. Further, the strategy advocates for both biosafety and biosecurity to guarantee that the development and utilization of biotechnology aligns with overarching ethical principles, as well as international best practices. This approach aims to prevent unintentional or intentional harm to individuals, animals, and the environment.

While some R&D needs address short-term challenges in scaling up existing technologies (5-7 years), others are dedicated to fostering long-term breakthroughs in pioneering technological advancements (up to 20 years). Recognizing the overarching objective of increasing supply chain resilience, the strategy also underscores the importance of infrastructure development and enhanced data utilization to proactively identify and mitigate supply chain bottlenecks. According to the US government, interdisciplinary research and groundbreaking discoveries are considered the primary tools to ensure long-term global leadership of the US bioeconomy.

Overall, the comprehensive new strategy described by the EO has certain limitations, chief among them being that the aspirations described therein largely exist as unfunded mandates. It remains to be seen whether the US Congress will appropriate adequate funding to enable their achievement. As of now, the strategy primarily serves as a guiding framework to facilitate cooperation and coordination between the public and private sectors. The dedicated implementation plan also mandated by the EO as due in June of 2023 was at the beginning of 2024 several months late. The EO Tracker is an interesting instrument that can be considered also by other countries or regions engaging in bioeconomy policy and program implementation.[29]

Asia/Pacific

Major developments until 2020: According to the 2020 Global Bioeconomy Policy Report, **Japan, Malaysia** and **Thailand** in the Asia-Pacific region have implemented dedicated bioeconomy strategies. These strategies primarily emphasize high-tech advancements and industrial development within the bioeconomy sector. Key areas of focus include enhancing human health through medical innovations, collaboration with the bioindustry for the production of bio-based products such as marine biodegradable plastics, and establishing centres of excellence for bioeconomy research. Additionally, countries like **China, India, Russia, South Korea**, and **Sri Lanka** have developed bioeconomy-related strategies with a strong emphasis on high-tech approaches and biotechnology. Bioenergy plays a significant role in countries like **India**, **Indonesia** and **New Zealand**, with **Australia's Queensland** state having a specific roadmap for bioindustry development. **New**

[29] https://www.datawrapper.de/_/8xal2/.

Zealand,[30] on the other hand, prioritizes growth and value-creation in its primary industries. In addition, its bioeconomy is driven by a 15-year emissions reduction plan, which specifically refers to actions for the development of a circular bioeconomy strategy.[31]

Major developments since 2020: **China** has outlined its future direction for "National Economic and Social Development" through its 14th five-year plan, which extends until 2025, along with long-range objectives for 2035. The plan defines the bioeconomy as based on the protection, development, and utilization of bioresources to drive the development of life science and biotechnology to promote a blueprint for the sustainable development of human society. Industrial biotechnology, in particular, is of special importance in achieving these goals.

Over the past decade, official government documents have demonstrated **China's** keen interest in advancing biotechnologies. However, a dedicated bioeconomy strategy had been absent until the recent development of the 14th five-year plan for bioeconomy development. With this plan, **China** has taken a significant step forward, placing an even greater emphasis on the development of the bioeconomy. It demonstrates **China's** growing commitment to bioeconomy development and aligning it with its broader national objectives. In the following section, we summarize the details of the new Chinese dedicated bioeconomy strategy.

Further, the **Japanese** national bioeconomy strategy is subject to annual revisions. **Japan** also conducts a comprehensive review of its strategy every five years. A dedicated working team is currently involved in revising the bioeconomy strategy in preparation for 2024, marking the fifth year of the strategy's implementation. The **Japanese** government has committed to a substantial fund, approximately 500 billion yen,[32] for bio-manufacturing, showing Japan's ongoing efforts to advancing its bioeconomy.

While **India** does not feature an explicit bioeconomy policy or strategy paper, there are high level announcements by the **Indian** government to facilitate fast growth in the nation's bioeconomy.[33] It may be expected that the various bioeconomy-related policies in India will be consolidated in a dedicated strategy in the future. It is noteworthy that **India** took the initiative to place a bioeconomy policy paper on the G20 agenda.[34]

Further, the **Thai** Government introduced the Bio-Circular-Green Economy (BCG) model as a strategic framework for national development and post-pandemic recovery. This model prioritizes the application of science, technology, and innovation to leverage Thailand's comparative advantage in biological and cultural diversity, transforming it into a competitive advantage.[35]

China

The Chinese 14th five-year plan for the bioeconomy[36] identifies four key areas of development:

(i) biomedicine for life and health,
(ii) modernization of agriculture,
(iii) green and low-carbon biomass applications, and
(iv) national biosecurity risk prevention and control.

The last point highlights the ongoing challenge in China to cope with the COVID-19 pandemic, which has led to new efforts to integrate

[30] New Zealand had no bioeconomy related strategy except a bioenergy policy - it is only now developing a bioeconomy focused one.
[31] https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-reduction-plan/
[32] Around 33,677,750 USD or 30,724,930.62 EUR.
[33] Union Minister Dr Jitendra Singh says, India is set to achieve $150 billion Bio-Economy by 2025, which stood at over $100 billion in 2022.
See:https://www.pib.gov.in/PressReleasePage.aspx?PRID=1951126
[34] https://t20ind.org/research/circular-bioeconomy-and-sdgs-proposals-for-the-g20/
[35] https://www.bcg.in.th/eng/background/
[36] https://www.gov.cn/zhengce/zhengceku/2022-05/10/content_5689556.htm

measures of prevention and control potential future pandemics into the country's bioeconomy development plan.

Biomedicine for life and health

Within the biomedicine field, the Chinese government pursues a strategy change from "treatment-centred medicine" towards "health-centred medicine" and thereby contributes to the "healthy China strategy." The Chinese government sees enormous potential in improving disease prevention and early screening through a combined promotion of high-tech precision medicine, including advanced diagnostic technologies, high-end medical imaging equipment, and intelligent, miniaturized, and multifunctional medical devices with genetic testing. The use of genetic engineering for the development of vaccines and therapeutic solutions for infections is also prioritized. Further, the new strategy promotes advances in clinical care by emphasizing the development of technologies such as microfluidic chips, automation, and cell and gene therapy products. The new Chinese development plan also aims to strengthen traditional Chinese medicine by promoting research to evaluate the efficacy of traditional approaches and the use of the knowledge for research and innovation. In particular, the integration of traditional Chinese and Western medicine is emphasized, along with the development of biological control and green prevention and control technologies.

The Chinese plan recognizes the vast potential of utilizing advanced information technologies to drive innovation in biotechnology within the field of biomedicine, explicitly addressing the development of a bioinformatics industry, capitalizing on artificial intelligence, big data, and advanced technologies. According to the plan, advancements in the bioinformatics industry are expected to significantly contribute to improved disease research, personalized medicine, and remote monitoring. To achieve these goals, the Chinese plan promotes specific tools such as data sharing facilitated by technologies like 5G, blockchain, and the Internet of Things. These technologies are aimed at enhancing drug traceability, connecting health data, and supporting regional health initiatives. Prioritizing the integration of online and offline medical services, convenience services, and the application of health big data in various healthcare areas is also a key focus of the plan.

Modernization of agriculture

The Chinese understanding of biological agriculture refers to four main areas, including biobreeding, bio-fertilizers, bio-feeds, and biopesticides. Within the 14th five-year plan, the government aims to respond to new trends, transitioning from "solving subsistence" towards "nutrition diversification," while the people's new expectations for higher levels of food consumption should be met. In the agricultural sector, the new Chinese plan follows a strategy of sustainable intensification to increase productivity and quality of agricultural production on existing land with positive environmental and social impacts. Technological advancements to reach this goal include biological breeding and technologies like genome-wide selection, systems biology, and synthetic biology to enhance breeding, production, and processing capabilities. The development of green agriculture, agricultural waste utilization, and precision biotechnology in agriculture are also encouraged to improve land and resource utilization efficiency. Improving food security and the quality of nutrition continue to present a central societal goal for the Chinese government.

Green and low-carbon biomass applications

Chinese authorities see tremendous potential in the development of advanced bioengineering and biomanufacturing technologies and to replace fossil fuels and create new bio-based chemical materials in the transition from fossil energy to green, low-carbon, and renewable energy sources. The strategy is focusing on researching and cultivating new biomass energy technologies, promoting biofuels, and integrating the biochemical industry with biomass

combustion blending standards. Efforts are being made to enhance the development of key technologies, like algae biofuels. The new Chinese strategy also emphasizes the use of biological technologies for environmental protection, such as water denitrification and phosphorus removal, soil remediation, and waste utilization.

Political and legal framework

The new Chinese bioeconomy development plan places considerable emphasis on technological advancements. It also dedicates a substantial section to governance, outlining the necessary enhancements to the political and legal framework to facilitate the growth of the bioeconomy. These include:

(i) Improvements of the drug and medical device approval process.
(ii) Improvements of the basic medical insurance system in order to ensure accessibility, affordability, quality, and coordination in healthcare delivery.
(iii) A better protection of intellectual property to foster innovation in the fields of pharmaceuticals and biological resources, including data protection rights.
(iv) Strengthening the utilization of financial funds, venture capital, credits and foreign investments to support the development of the bioeconomy and the protection of biodiversity in developing countries.
(v) Ensuring a continuous influx of interdisciplinary trained professionals and experts in fields such as life sciences, medicine, physics, informatics, and related disciplines.
(vi) Commitments to actively engage in global governance related to the bioeconomy. The proposed measures include collaboration on global health challenges, the internationalization of China's pharmaceutical industry, and biodiversity conservation on a global scale.
(vii) Establishing specialized regional centres to implement pilot projects in areas such as cell therapy, traditional Chinese medicine, medical device registration, or fostering comprehensive innovation.
(viii) Developing several bioeconomy pilot zones taking the lead in piloting reform measures in in science, technology and innovation, production application, market supervision, finance, pricing, and international cooperation, thus encouraging the development of new technologies, new industries, new business models and formats.

Europe

Major developments until 2020: As shown in the 2020 Global Bioeconomy Report, within Europe, the **European Union** plays a pivotal role in shaping national bioeconomy policy strategies. In 2010 **Germany** published the first dedicated national bioeconomy research strategy, followed by a policy strategy in 2013. The **European Commission** presented a bioeconomy strategy for Europe in 2012, which prompted the development of national bioeconomy strategies by **EU Member States**. **Finland** emerged as a prominent bioeconomy nation in Europe with the publication of a dedicated policy strategy in 2014. Between 2014 and 2020, eight European countries, including **Austria, France, Ireland, Italy, Latvia, the Nordic Countries, and Spain**, have adopted dedicated bioeconomy policy strategies. Furthermore, the **United Kingdom**,[37] a former EU Member State, also formulated its own dedicated bioeconomy strategy before 2020. **Germany** published an updated strategy in 2020.

[37] The UK has meanwhile withdrawn its national bioeconomy strategy.

Several European countries, including the **Netherlands** and **Sweden**, adopted comprehensive bioeconomy-related strategies until 2020. In **Belgium** the region of Flanders developed a sub-national bioeconomy strategy. Additionally, according to the 2020 Global Bioeconomy Policy Report, European countries frequently incorporated the bioeconomy into wider green or blue growth strategies or within circular economy strategies. **Portugal's** bioeconomy roadmap highlighted its key role and emphasis on the "blue" bioeconomy, which entails knowledge-based production and utilization of aquatic (i.e., "blue") bioresources for innovative products, processes, and services. Finally, the 2020 Report shows that many European regions have integrated the bioeconomy into their policy agendas, resulting in the formulation of sub-national bioeconomy strategies. **Regions in France, Germany, Norway** and **Spain, such as Andalucía, Baden-Wurttember, Basque Country, Bavaria, Castilla León, Extremadura, Grand Est, Haute-de-France, Innlandet, Ostfold, Rogaland** and **Trondelag, , , ,** have developed dedicated strategies to promote bioeconomy initiatives.

Major developments since 2020: The bioeconomy policy in the **EU** is evolving dynamically. Particularly noteworthy, compared to the documented situation until 2020, is the publication of a "Progress Report" in 2022 on the implementation of the updated **EU** bioeconomy strategy and its Action Plan in the EU by the **European Commission**, which also includes a dedicated chapter on the future strategic development of the bioeconomy in the **EU**. According to the **EU** progress report, there has been notable advancement in the adoption, implementation, and coherence of national and sub-national bioeconomy strategies over the past decade. Currently, **11 European Union Member States** have specific bioeconomy strategies, while seven **Member States** are in the process of developing their strategies. The 2020 report covers these developments. However, significant new efforts have occurred in four countries: **Austria**, **Finland**, **Ireland** and **Portugal**. **Austria**, **Ireland,** and **Portugal** have expanded their bioeconomy strategies by publishing dedicated action plans, while **Finland**, which initially published its strategy in 2014, has updated its approach aiming to double the value added from the bioeconomy by 2035 in an ecologically, socially, and economically sustainable way. Next, we will systematically summarize these two advancements.

European Union

The progress report was preceded by the following developments: In October 2018, the EU published a revised Bioeconomy Strategy and Action Plan titled "A Sustainable Bioeconomy for Europe: Strengthening the connection between economy, society, and the environment."[38] This update introduced new priorities for the bioeconomy (e.g., understanding the ecological boundaries of the bioeconomy), emphasizing its role in climate protection and sustainable development in Europe. The updated strategy maintained the original five objectives for the bioeconomy that were part of the 2012 original bioeconomy strategy:

(i) Ensuring food and nutrition security.
(ii) Sustainable management of natural resources.
(iii) Reducing dependence on non-renewable resources.
(iv) Mitigating and adapting to climate change.
(v) Enhancing European competitiveness and job creation.

The Commission published the progress report on the implementation of the EU Bioeconomy Strategy in May 2022, which underscores the integration of the bioeconomy within the European Green Deal.

[38] https://knowledge4policy.ec.europa.eu/publication/sustainable-bioeconomy-europe-strengthening-connection-between-economy-society_en

The report emphasizes the significance of efficient bioeconomy governance to maximize synergies and navigate trade-offs during its implementation. It highlights the importance of bioeconomy policies that embrace all aspects of sustainability, including responsible management of land and biological resources within ecological boundaries, the promotion of sustainable value chains and consumption patterns, and social fairness and a just transition for all stakeholders involved.

Progress in the European Union bioeconomy

The Progress Report indicates that headway has been made towards achieving the primary objectives of the EU Bioeconomy Strategy. Several national and sub-national bioeconomy strategies are promoting cooperation across sectors and embracing sustainability principles, while investing in bioeconomy innovation. Notably, Central and Eastern European countries have made significant progress in bioeconomy development and consolidated political commitment and Research and Investment (R&I) frameworks through the establishment of the BIOEAST initiative.[39] Moreover, there is a growing mobilization of private investments and research in food and other bio-based industries, showcasing promising advancements. For example, the EU bioeconomy strategy led to the establishment of the Bio-based Industries Joint Undertaking (BBI JU), attracting private investments and promoting R&D in the European bio-based industry. With EUR 975 million from the European Commission and EUR 2.73 billion from the private sector (represented by the Bio-based Industries Consortium [BIC]), 142 bio-based industry projects focused on sustainable alternatives to fossil-based products were funded between 2014 and 2021. The successor, the Circular Bio-based Europe Joint Undertaking (CBE JU) partnership (2021-2031), aims to further strengthen the EU bio-based sectors. The CBE JU is endowed with an EU contribution of EUR 1 billion and a contribution of at least the same amount from the BIC. Together, these unique public-private partnerships have so far invested EUR 5.7 billion to support the European Green Deal and the UN Sustainable Development Goals.[40] Examples of other notable bioeconomy related initiatives are the inclusion of the construction sector into the bioeconomy New European Bauhaus[41]) and the EU Mission: Restore our Ocean and Waters.[42]

Overall, Europe's position in the global market for bio-based chemicals and materials remains strong. However, the progress report also identifies gaps in the current Action Plan that necessitate further attention. These include a need for enhanced management of land and biomass supply and demand to meet environmental and economic requirements in a climate-neutral Europe, as well as efforts to foster more sustainable consumption patterns.

Strategic outlook

The final section of the EU progress report is of particular significance. In this section, the Commission highlights potential future directions for the bioeconomy in the EU. Notably, the Commission sees the need to develop a bioeconomy that produces robust social outcomes, while operating strictly within the defined limits of the earth's resources and ecosystems (i.e., "planetary boundaries"). A significant measure towards attaining this objective is the expansion of the current *Knowledge Centre for Bioeconomy* and its EU *Bioeconomy Monitoring System*. The Commission emphasizes the importance of gaining a deeper understanding of

[39] https://bioeast.eu/

[40] European Commission, Directorate-General for Research and Innovation, European bioeconomy policy – Stocktaking and future developments: Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2777/997651

[41] https://new-european-bauhaus.europa.eu/index_en

[42] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters_en

the potential synergies and trade-offs linked to technology and policy options through better monitoring and integrated assessments.

These assessments should encompass a comprehensive analysis of the impacts of the socioeconomic and environmental systems in the bioeconomy, accounting for interconnections and feedback mechanisms. When addressing the projected "biomass gap" between future demand and supply of biomass for food, materials, and energy, special policy priorities should be given to environmental concerns. To enable such bioeconomy policies, the Commission argues for the development and implementation of an integrative assessment framework at the EU and national levels for understanding and resolving trade-offs on land-use to optimize the societal benefits from land, aquatic area and biological resources, including biodiversity and other ecosystem services.

Regarding the supply side, the Commission emphasizes the need to enhance the skills and qualifications of the European Union's workforce to effectively participate in emerging innovative bio-based value chains. Furthermore, it stresses the importance of strengthening research and innovation through public and private investments to promote long-term transformative changes in the bioeconomy.

Regarding the demand side and based on the holistic approach of the bioeconomy in the EU, the Commission suggests that consumption patterns need to become more sustainable to guarantee the environmental integrity of the bioeconomy. It is argued that consumer-driven bioeconomy action can trigger high investments in sustainable bioeconomy businesses and drive the sustainable transformation of regions and Member States. Consequently, the Commission will put more focus on the total demand for biological resources aiming to facilitate the transition to more sustainable consumption practices. Additionally, the progress report provides an overview of research and innovation projects of relevance for the bioeconomy and funded through Horizon Europe, the EU's framework program for research and innovation. Finally, the Commission highlights the importance of enhancing stakeholder engagement at all levels for a successful implementation of the bioeconomy, as it enables a connection between policy initiatives and local realities.

Finland

In 2014, Finland introduced its first comprehensive policy plan for the bioeconomy titled "The Finnish Bioeconomy Strategy – Sustainable growth from bioeconomy."[43] This strategy is significant, being one of the pioneering national bioeconomy strategies in Europe. It outlined a comprehensive set of objectives and actions, driving Finland to emerge as the foremost bioeconomy leader in Europe. The updated Bioeconomy Strategy of 2022 builds upon the progress made so far, while also adapting to the latest advancements and evolving knowledge base.

The updated Finnish strategy is committed to the EU's European New Green Deal and the SDGs. It explicitly embraces a holistic approach to a sustainable bioeconomy, encompassing social, economic, and environmental components. In addition, the Finnish strategy is based on the concept of a circular economy, which aims to valorize the natural resources available in the form of biomass—organic matter found in forests, agriculture, the sea, and fresh water—efficiently and in an environmentally friendly manner to produce food, energy, products, and services.

An important policy innovation of this updated national bioeconomy strategy is that it postulates a quantitative target for the bioeconomy: The main objective of the strategy is to double the value added generated by the bioeconomy between 2022 and 2035 by fostering economic

[43] https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/163969/VN_2022_5.pdf

growth and job creation through sustainable solutions that produce high-value products and services. In 2019, the value added by the bioeconomy in Finland amounted to EUR 26 billion. The strategy sets a target to accelerate the annual growth rate of the bioeconomy's value added from 3% to 4%. If the objective is achieved, the Finnish bioeconomy's value added is projected to reach EUR 50 billion by 2035.

In contrast to the strategies pursued by the United States and China, the Finnish approach places less emphasis on promoting the economic growth of the bioeconomy solely through increasing bio-based production volumes. Instead, it recognizes the importance of shifting the focus towards investments and production methods that generate higher value added from existing biomass, thereby enhancing the environmental performance of the bioeconomy. According to the updated Finnish strategy, the bioeconomy is positioned to have a vital role in facilitating the transition towards a more environmentally sustainable society. It offers solutions to address global challenges, such as those related to climate change and biodiversity. By actively engaging bioeconomy solutions in the green transition, it is more likely to make socially and regionally equitable changes, while ensuring long-term sustainability.

The Finnish strategy encompasses a wide range of policy measures to achieve these objectives. These measures include supportive policies for research, development, and innovation (RDI), as well as demand- and supply-side support for upscaling and commercialization.

Research, development and innovation policies

The Finnish strategy recognizes the significance of advanced biotechnology, including genetic engineering and the application of AI. However, unlike the US and Chinese strategies, the emphasis on these aspects is rather modest. The Finnish RDI policies primarily concentrate on enhancing the efficient and sustainable utilization of existing biomass reserves within an advanced circular economy framework. The Finnish strategy includes specific measures to advance its goals:

(i) Establishing partnerships between research and business sectors to facilitate the development of business models and products that integrate re-use and recycling potentials right from the initial stages of product design, development, and marketing.
(ii) The development of model regions and demonstration plants for new, innovative bio-products that showcase fully integrated circular economies.
(iii) Advancing bioeconomy monitoring capabilities to enhance companies' knowledge bases in efficiently allocating and cascading the use of biomass.

Overall, these measures should promote sustainable practices and innovation within the bioeconomy, fostering collaboration between research and business sectors while encouraging the adoption of circular economy principles.

Supply and demand side policies

The upscaling and commercialization of bio-based products are acknowledged as significant challenges in all the discussed bioeconomy strategies. In recognition of this concern, the Finnish strategy encompasses a set of targeted measures to support the growth of the bioeconomy. On the supply side, the measures include subsidies for bio-based industries, improved partnerships between public and private finance to generate sufficient venture capital, streamlining the permission process for bioproduction plants to create a competitive environment, and the education of a specialized workforce tailored to the needs of the bioeconomy. On the demand side, the Finnish strategy focuses on increasing stakeholder and consumer acceptance of bio-based products. This is pursued through initiatives such as the development of information tools that provide insights into the carbon footprints of different

products, thereby enabling informed decision-making and enhancing the market demand for sustainable alternatives. The Finnish strategy recognizes the importance of international co-operation, particularly with Nordic European countries to advance the bioeconomy. Collaboration and partnership at the international level are seen as crucial for driving progress in the bioeconomy.

By implementing these measures, the Finnish strategy addresses the challenges associated with upscaling and commercialization, paving a likely pathway for the successful growth and adoption of bio-based products within the bioeconomy. The Finnish strategy specifies plans for various economic sectors (particularly the forestry sector) and proposes establishment of a comprehensive monitoring system to track progress towards the defined goals.

Austria

The national bioeconomy strategy in Austria—adopted by the Austrian Government in 2019—envisions an economy that harmonizes technology and ecology. It is designed to address global societal challenges such as climate change, food and water scarcity, and environmental pollution. Further, the strategy should promote the decarbonization of Austria's society and economy.

The Austrian strategy aligns closely with the goals of the EU strategy and the principles of the European Green Deal, emphasizing a robust focus on climate and environmental concerns. It expects the bioeconomy to play a significant role in reducing greenhouse gas emissions by 2030 and contributing to a more sustainable future.

Recently, in 2022, the Austrian Government released a bioeconomy action plan to effectively implement the targets and goals outlined in the 2019 bioeconomy strategy.[44] The development of policy measures for this plan is noteworthy in terms of governance, as it adopted a bottom-up and inclusive stakeholder approach promoting a collaborative and participatory decision-making process to bioeconomy governance. A total of 20 events took place, involving over 400 experts from businesses, research institutions, associations, social partners, NGOs, and public entities. Around 800 inputs were gathered during these events, which were then consolidated into over 100 measures through an aggregation processes. Each measure underwent evaluation and prioritization by the three ministries involved in the process. The aim was to refine the content of the measures and identify high-priority actions aligned with the objectives of the Austrian Bioeconomy Strategy. Therefore, the Bioeconomy Action Plan is structured into 11 thematic areas, further divided into specific action fields containing a total of 113 defined measures to be implemented in an all-of governance approach.

Research and development

Like many other strategies, the Austrian bioeconomy action plan recognizes the crucial importance of R&D activities in the growth of a sustainable bioeconomy. Some R&D-related policy measures within the Austrian bioeconomy action plan are focused on progress in the field of precision agriculture. Here, the emphasis is on sustainable and productive farming practices that maximize yields, reduce waste, and contribute to the overall sustainability of the bioeconomy.

However, like the Finnish Strategy and overarching EU bioeconomy model, the majority of the R&D-related policy measures in the Austrian bioeconomy action plan aims to optimize the efficient and sustainable utilization of the available biomass reserves by implementing advanced circular and sharing economy frameworks. Examples include:

(i) Measures to promote innovations in the development of fibres and textiles to be used within sustainable sorting and recycling processes,

[44] https://www.bmk.gv.at/themen/klima_umwelt/klimaschutz/biooekonomie/aktionsplan.html

(ii) the development of environmentally safe bio-based plastic substitutes (such as biodegradable and non-micro-plastic-generating plastics), and
(iii) the establishment of demonstration facilities for biorefineries.

The Austrian innovation policies promote partnerships between research and business and public funders to create inventions and new business models that ensure the responsible and efficient use of biomass throughout its lifecycle, especially for the forest and wood sectors. Finally, the Austrian strategy acknowledges the significance of incorporating knowledge and insights from the humanities, social sciences, and cultural studies into the development of policies, recognizing the profound societal challenges that accompany the transition to a bio-based economy.

Supply and demand side policies

On the demand side, the Austrian action plan aims to encourage changes in consumer behaviour. The consumption of regional products is to be promoted and food retailers are encouraged to provide food in a demand-responsive manner that minimizes food waste. It also includes interventions by the Austrian government in the fuel market to gradually increase the minimum blend of biofuels. Furthermore, the bioeconomy action plan acknowledges the significance of raising awareness and conducting image campaigns among all stakeholders to enhance acceptance for environmentally and climate-friendly bioeconomic models. On the supply side, the action plan emphasizes new standard systems that reduce transaction costs in new markets for bio-based products. Examples include certifications in trade with secondary bioresources derived from waste. Direct government subsidies primarily target the promotion of a sustainable forest and wood industry.

Finally, it is worth mentioning that the bioeconomy action plan in Austria emphasizes the importance of sustainable spatial planning models. These efforts, which are in line with the EU's plans, aim to prevent further land sealing and preserve the existing agricultural land for biomass cultivation as much as possible. Overall, the Austrian bioeconomy action plan reflects a strong ecological focus. The bioeconomic transformation is understood as a broad societal process that involves a multitude of stakeholders.

Portugal

Very recently, the Portuguese government released a new action plan for advancing a sustainable bioeconomy, titled "Plano de Ação Para a Bioeconomia Sustentável Horizonte 2025"[45] (Action Plan for Sustainable Bioeconomy Horizon 2025). In alignment with the European Green Deal, the plan places a strong emphasis on prioritizing the preservation and sustainable use of biological resources, while explicitly referencing the Sustainable Development Goals (SDGs). These guiding principles establish a framework for several recommended measures designed to achieve the following overarching objectives:

(i) Promote bio-based economic activities with low carbon intensity
(ii) Guaranty food and nutrition security
(iii) Sustainable use of renewable natural resources and safeguard biodiversity
(iv) Promote innovative and bio-based industries using smart/intelligent processes
(v) Promote competitiveness and employment at local and regional scales
(vi) Promote consumer awareness and sensitization

[45] https://apambiente.pt/sites/default/files/_A_APA/Iniciativas_transectoriais/bioeconomia/PABS_Dez2021.pdf

Coordinated policy action across bioeconomy sectors

The Portuguese action plan underscores the necessity for coordinated policy actions to foster the growth of a sustainable bioeconomy, encompassing various biological sectors and leveraging the efficiency of transformation through the adoption of Industry 4.0 models and innovations. The shift towards a new bio-based economy involves enhancing the valuation of natural biological capital to strengthen local businesses and communities in sectors such as agriculture, forestry, fishing, aquaculture, water management, and processing. Consumers are recognized as central beneficiaries in bioeconomy transitions. The action plan also outlines key initiatives, including promoting sustainable biological resource use, developing more resilient value chains, reducing dependence on fossil resources, striving for carbon neutrality, and bolstering regional development. The detailed plan articulates five axes for the effective implementation of bioeconomy policies:

(i) Incentivize sustainable production based on regional resources
(ii) Promote circular and sustainable bio-industries
(iii) Bioeconomy and sustainability monitoring
(iv) Promote research and innovation
(v) Education and training

Governance

To achieve its objectives, the Portuguese Government adopts an integrated governance approach. Specifically, the action plan outlines the establishment of an "Interministerial Commission for Sustainable Bioeconomy," tasked with overseeing policy alignment with the principles of a sustainable bioeconomy and relevant sectoral policies. Additionally, a coordination group, headed by the Portuguese Environment Agency, is tasked with coordinating decision-making, promoting intersectoral cooperation, and monitoring the implementation of bioeconomy-related policies. This group incorporates representatives from various government sectors and actively engages civil society representatives from education, scientific research, environmental NGOs, business associations, and other relevant stakeholders.

Ireland

In the "2018 National Policy Statement on the Bioeconomy"[46], Ireland developed its long-term vision and guiding principles for a striving Irish Bioeconomy. In detail, this document emphasizes Ireland's commitment to harness its bioeconomy's potential in alignment with strategic objectives on sustainable development, climate action, circular economy, competitiveness, and rural/regional development. With the recent publication of the "Bioeconomy Action Plan 2023-2025"[47] in October 2023, the Irish government has now taken a further significant step towards turning Ireland into a global bioeconomy leader.

Similar to other states with dedicated bioeconomy strategies, the Irish government envisions the bioeconomy playing a pivotal role in achieving a variety of core national development goals. This includes:

- "Boosting employment and new business opportunities in rural, regional, urban, and coastal areas, through new and innovative products, services, and technologies,
- increasing food and energy security,
- supporting climate action by displacing fossil fuels,

[46] https://assets.gov.ie/2244/241018115730-41d795e366bf4000a6bc0b69a136bda4.pdf
[47] https://www.gov.ie/en/publication/a1bb6-bioeconomy-policy/#irelands-bioeconomy-action-plan-2023-2025

- promoting a circular economy and reducing waste,
- providing high-value diversification opportunities for transforming the agri-food system, and
- leveraging research, development, and innovation capabilities to address Ireland's bioeconomic, societal, and environmental challenges."[48]

The recently released action plan takes into account advancements at both the EU and international levels, notably acknowledging the EU Commission's progress report on the bioeconomy strategy. It also considers the EU Council conclusions on the bioeconomy.

This awareness of global and regional developments ensures the alignment of the national Irish action plan with broader international efforts and best practices in the field of bioeconomy.

Defining policy actions

The action plan explicitly acknowledges the European recognition of the circular economy's potential benefits for economies and societies. Moreover, the plan takes a comprehensive approach to the bioeconomy, as outlined in the seven key action pillars set by the Irish Government.

(i) **Governance and awareness:** Enhance understanding and awareness of the bioeconomy, fostering coordination among policies.

(ii) **Research, development, and innovation:** Integrates bioeconomy opportunities into national research programs, emphasizing scaling-up through pilot projects and knowledge transfer.

(iii) **Nature, climate, energy, and circular economy:** Aligns bioeconomy development with sustainability, circularity, and the transition to a net-zero economy.

(iv) **Agriculture, food, forestry, and the marine environment:** Focuses on biomass and biomaterial generation, supporting bioeconomy initiatives, advisory services, and material recirculation.

(v) **Communities, regions, and cities:** Boosts local and regional bioeconomies through improved governance, funding utilization, and support for social enterprises.

(vi) **Industry and enterprise:** Facilitate the transition from piloting to commercialization, guiding bioeconomy actors, enhancing sustainability, circularity, and coordinating investment.

(vii) **Knowledge and skills:** Promote bioeconomy education at all levels, ensuring continuous learning and professional development.

The Bioeconomy Action Plan 2023-2025 marks Ireland's next step in advancing a holistic bioeconomy. It is supported by a High-Level Bioeconomy Implementation and Development Group that brings together 11 government departments and 8 agencies. Recent years have also seen the integration of the bioeconomy across major sectoral strategies in areas such as climate, research and innovation, rural and regional development, and smart specialization.

Sub-national, bioeconomy strategies

The last section of this report addresses subnational bioeconomy strategies. As mentioned earlier, various policy initiatives, particularly

[48] Government of Ireland, Action Plan for the Bioeconomy 2023-205, p. 6.

within the **EU**, have supported and stimulated the formulation of sub-national government strategies in many countries. These strategies are typically developed by political authorities at the sub-state level in federal systems, rather than the central government. Our research has identified three relevant sub-national bioeconomy strategies published in the past three years**: Saxony-Anhalt** in **Germany**, the state of **Pará** in **Brazil**, and **Queensland** in **Australia**, where an existing strategy has been updated. These strategies are based on the specific characteristics, resources, priorities, and challenges of each region. However, all strategy documents reflect the overarching objective to improve the use of bio-based resources in a sustainable and inclusive manner, fostering economic growth, protecting the environment, and enhancing social well-being.

The Central German Mining Region

The Central German Mining Region, also known as the Mitteldeutsches Revier, refers to a region located in the triangle of the federal states of Saxony-Anhalt, Saxony, and Thuringia. The region has been heavily influenced by coal mining and the chemical industry that developed around this fossil resource. Like other coal-driven industrial regions, Central Germany has been affected by the decline of these industrial cores and is facing significant structural challenges today. The bioeconomy has been identified as a key strategic area that can leverage the region's local strengths for successful structural transformation and economic growth while playing a crucial role in achieving climate targets.

Given the interest expressed by companies in the bioeconomy sector to invest in the region, the strategic policy document published by the state government of Saxony-Anhalt emphasizes the necessity to establish the region as a model for the bioeconomy.[49] The document highlights the importance of implementing flagship projects to attract international corporate investments. Additionally, it emphasizes the need to strengthen R&D, workforce development, and industrial infrastructure development to support sustained growth. Moreover, there is a focus on actively shaping the region's reputation as a leading model for the development of a bio-based industry. The production of bio-based platform chemicals and their use in regional value-added chains in the chemical industry can provide new jobs while, at the same time, contributing to the transition towards a climate-friendly chemical industry.

Queensland, Australia

The Queensland Government launched the State's first Biofutures Roadmap and Action Plan in 2016 with the aim to establish Queensland—traditionally a major mining region, now looking to transition—as a world-leading and sustainable region for the bio-based industry. The term "Biofutures" refers to the industrial biotechnology and bioproducts sectors that develop sustainable products from organic and waste resources instead of fossil fuels. This involves innovative technologies that convert feedstocks from agriculture, forestry, algae, and waste into various bioproducts such as chemicals, fuels, rubber, cosmetics, and textiles. These bioproducts offer renewable and environmentally friendly alternatives to traditional chemical and fuel refining processes. As is often the case in regional strategies, the bioeconomy is recognized as a catalyst for economic development, providing avenues for innovation, job generation, and growth within the region. The roadmap focuses on innovation, creating jobs, and attracting investments in bio-based industries. It also outlines sub-strategies for developing advanced biofuels, bioplastics, and biochemicals.

In 2022, the Queensland Government released an updated action plan that recognized the

[49] https://www.mitteldeutschland.com/wp-content/uploads/2021/06/010621_biooekonomie-strategiepapier.pdf

achievements of the previous strategic initiative, which was launched in 2016.[50] The revised document specifically recognizes noteworthy milestones achieved in the biofuel industry, such as the successful development of Australia's first sustainable aviation fuel. Furthermore, the document reaffirms Queensland's commitment to promote the local biofuel market through collaborations with key sectors such as aviation, construction, maritime, and transport. The action plan comprises three main efforts:

(i) Creation and maintaining a favourable policy environment that supports the growth of the Biofutures industry.
(ii) Provision of additional assistance for targeted initiatives to develop specific industries.
(iii) Identification and promotion of investment opportunities within Queensland.

The aforementioned strategy document by Saxony-Anhalt involves a comprehensive analysis of the existing potentials in the Central German Mining Area to facilitate the transition from carbon-intensive and fossil-based regional economic systems towards a bioeconomy model region. The strategy emphasizes the promotion of R&D activities in the region and the establishment of partnerships between industry and research institutions, capitalizing upon the region's comparative advantages. Additionally, the strategy aims to coordinate and integrate policy actions across three German federal states.

On the other hand, the Queensland roadmap assigns the private sector a prominent role and policy actions primarily target the establishment of new bio-based industries. Queensland highlights the successful development of the sustainable aviation fuel industry as a major achievement. This clearly demonstrates that significant investments by the private sector are crucial for the realization of bioeconomic transformations. As highlighted in an upcoming article published in the Bioeconomy Journal,[51] based on findings from a global expert survey, it is evident that the commercialization and scaling up of the bioeconomy continue to present significant challenges.

Pará, Brazil

The state of Pará in Brazil, characterized by its expansive Amazon rainforest, is pioneering the development of an inclusive bioeconomy. With 78% of its territory covered by native vegetation, Pará aims to develop a forest-based bioeconomy that gives priority to biodiversity and socio-biodiversity.[52] This strategic vision extends beyond mere sustainable production, using a holistic approach that incorporates green infrastructure, job creation, and the promotion of low-carbon socio-economic growth.

The state government of Pará officially launched its Bioeconomy Strategy during the 2021 World Bioeconomy Forum in Belem. In accordance with the state's policy on climate change the regional government mandated the creation of a State Bioeconomy Plan within a year. The decree emphasized the need for collaboration with public entities, the private sector, NGOs, research institutions, and representatives of indigenous peoples and traditional communities.

Structured around three core axes, the State Bioeconomy Strategy focuses on research, development, and innovation. This axis aims to apply scientific knowledge for inclusive socio-economic and environmental benefits. The second axis, Cultural Heritage and Genetic Knowledge, emphasizes the recognition, protection, and valorization of traditional practices. It integrates these practices into the state's low-emission socio-economic development policies, ensuring socio-environmental

[50] https://www.statedevelopment.qld.gov.au/__data/assets/pdf_file/0023/72239/biofutures-roadmap-and-action-plan-june-2022.pdf

[51] https://www.sciencedirect.com/science/article/pii/S2667041023000137

[52] https://www.semas.pa.gov.br/wp-content/uploads/2023/01/Plano-Estadual-V9_pg-simple-2-1.pdf

safeguards and protection of the genetic heritage associated with cultural knowledge and biodiversity. The third axis, sustainable production chains and businesses, strives to enhance the value of biodiversity products.

By emphasizing sustainable development, cultural preservation, and biodiversity-based economic growth, Pará sets a precedent for regions worldwide grappling with similar environmental and socio-economic imperatives.

Global initiatives

In recent years, the bioeconomy agenda has received increased attention in global initiatives. While the SDGs do not explicitly mention bioeconomy, their integrative approach is coherent with the theory and concepts of the bioeconomy and the SDG agenda has provided some impetus for the bioeconomy at the global level. Additionally, the three Global Bioeconomy Summits all had strong and explicit linkages to the SDGs and the G20, the UN, and some of its organizations have explicitly adopted bioeconomy initiatives in recent years.

United Nations (UN): In the context of the UN, the initiative by the FAO in 2023 is noteworthy, as it includes sustainable and circular bioeconomy for transforming food systems, climate action, and biodiversity in its new science strategy.[53] The policy of the FAO states that "bioeconomy can be a key solution pathway for sustainable agrifood systems transformation to become more efficient, inclusive, resilient, and sustainable, while leaving no one behind." It stresses that the FAO's bioeconomy activities are closely aligned with the goals of the Organization's strategies and relevant action plans on mainstreaming biodiversity across agricultural sectors, climate change, science and innovation, and corporate environmental responsibility. In view of the FAO's international role, it shall contribute to "(i) facilitating the deployment of sustainable bio-innovations that increase resource use efficiency, improve environmental outcomes in agrifood systems and prevent pollution; and (ii) providing support to countries, regions and institutions in developing and implementing integrated, evidence-based bioeconomy strategies, policies and programmes." The FAO has the ambition to "(i) consolidate FAO's role as a leading global convening body on bioeconomy for sustainable food and agriculture; (ii) empowering FAO Decentralized Offices to sustain the impact and scale up bioeconomy solutions on the ground; and (iii) further improving the knowledge base, reporting and consolidation of lessons learned based on key performance indicators." Also, some other UN organizations have started to pay attention to bioeconomy, such as UNIDO, which has released a position paper entitled "Strengthening the global bioeconomy."[54]

The **G20** undertook an initiative under the Indian Government's chair in 2023 and issued a document entitled "Circular Bioeconomy and SDGs: Proposals for the G20."[55] Under the Brazilian chair of the G20 in 2024, the so-called Sherpa Track features working groups and task forces (one towards launching a Global Alliance against Hunger and Poverty and another for Global Mobilization against Climate Change) and a Bioeconomy Initiative.[56]

The **Global Biofoundry Alliance** has recently been established to coordinate activities worldwide. (https://www.biofoundries.org) was established to coordinate activities of synbio worldwide.

IACGB – Global Think Tank Initiative: Further global bioeconomy developments are fostered by the strengthened International Advisory Council on Global Bioeconomy (IACGB). This

[53] https://www.fao.org/3/nn652en/nn652en.pdf
[54] https://www.unido.org/sites/default/files/files/2022-07/BIO_ECONOMY_FACTSHEET.pdf
[55] https://t20ind.org/research/circular-bioeconomy-and-sdgs-proposals-for-the-g20/
[56] https://www.gov.br/mre/pt-br/embaixada-londres/press-releases/g20-brasil-2024

Council is an independent think tank composed of about 40 high-level bioeconomy leaders and experts from all hemispheres, representing different backgrounds and expertise. While the members of the IACGB serve in their personal capacity, many also advise the bioeconomy landscapes and governments of the countries or regions to which they relate. The IACGB initiates, designs, and organizes the Global Bioeconomy Summits, a leading global conference and platform for exchange and discussion of recent developments for a sustainable and circular bioeconomy worldwide. The IACGB meets regularly to debate current bioeconomy developments around the world and to frame options and ideals for future developments. The IACGB aims to inspire stakeholders around the globe to take its recommendations back to their home countries and facilitate their implementation. The IACGB recently released its statement at a conference in Hannover, Germany, entitled "One Planet - Bioeconomy Solutions for Global Challenges."[57]

Conclusion: Synthesizing results across countries and strategies

This report highlights the important bioeconomy advancements around the world since they were last documented in 2020.[58] The report captures the progress made over the past decade and highlights a global trend by governments, international organizations, companies, and civil society actors that are actively adopting bioeconomy strategies. It provides a systematic review of 19 official national and regional international bioeconomy strategy documents that have been instrumental in driving this advancement. The need for a bioeconomy policy update after just four years reflects significant policy dynamism, highlighting ongoing mega policy trends in recent times.

Recent mega policy trends

Notably, this updated report underscores the ongoing and growing significance of the bioeconomy for policymakers across the globe. As the graphical overview of the report demonstrates (Maps 1 and 2 above), countries with existing bioeconomy policies are actively engaged in continuous processes of reviewing and improving their policies, while new countries are also joining the global bioeconomy movement.

Established bioeconomy strategies, such as those of the EU and some European countries, have seen significant updates. Meanwhile, there have been particularly strong policy innovations in the US, China, Africa, and Latin America. These did not come about in isolation, but may have positive ripple effects among each other. Moreover, these innovations may have implications for global and multilateral initiatives, especially in the G20 2024 and beyond,[59] the UN system (in the context of the UN Food Systems Summit follow up processes), as well as the FAO.

Trends in agendas and contents

The analysis revealed that bioeconomy policy development is becoming increasingly comprehensive and complex. It applies to both the strategic goals in the field of bioeconomy and the advancement of political and legal frameworks to promote and regulate biotechnology

[57] https://www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/030437b6-8b93-11ee-b6ae-dead53a91d31/current/document/IACGB_Statement_Hannover_August_2023_published_DOI.pdf (With support of the Volkswagen Foundation.)

[58] Teitelbaum, L., Boldt, C., & Patermann, C. (2020). Global Bioeconomy Policy Report (IV): A decade of bioeconomy policy development around the world. https://gbs2020.net/wp-content/uploads/2020/11/GBS-2020_Global-Bioeconomy-Policy-Report_IV_web.pdf

[59] G20 Brazil https://www.g20.org/content/dam/gtwenty/gtwenty_new/document/G20_ECSWG-Knowledge_Exchange_on_Circular_Bioeconomy.pdf

and associated emerging technologies. In sum, bioeconomy is becoming more global, while also more adapted to regional, national, subnational, and even local contexts.

In recent years, there has been a tremendous increase in our knowledge regarding the bioeconomy, encompassing its scientific and societal prerequisites, as well as its ecological impacts. The new policies and strategies vividly reflect the enhanced understanding and the resulting learning effects. Finding solutions to enhance synergies and minimize trade-offs among economic, environmental, and social objectives are increasingly emphasized in the recent strategies we have analyzed.

The analyzed government documents exhibit a substantial convergence in outlining the fundamental societal objectives to be accomplished through expansion of the bioeconomy. The objectives include the pursuit of climate neutrality based on carbon-neutral bio-energy and bio-manufacturing to combat global warming, sustainable economic development to drive prosperity, innovations in agriculture and the food sector to ensure food and nutrition security, and improved health including better urban environments. These shared goals underscore the collective recognition of the bioeconomy's potential to address urgent global challenges and deliver positive outcomes across multiple sectors and dimensions of society.

Tackling global supply chain challenges has been identified as a new emerging trend in the development of the bioeconomy. The trend has been influenced by the COVID-19 pandemic and the rise of geopolitical tensions. The resilience of supply chains has become a national security issue, prompting states to invest in securing their supply chains against external risks. Policymakers, particularly in the pharmaceutical, food, and energy sectors, recognize the need to strengthen the bioeconomy to effectively address these urgent issues. By leveraging the bioeconomy's potential, countries aim to enhance supply chain resilience, promote domestic production, and reduce dependence on external sources, thereby ensuring greater stability in critical sectors.

However, these policies present a double-edged sword, as they entail both opportunities and benefits at a price of costs and challenges. While the development of the bioeconomy can contribute to addressing global supply chain problems, it is also important to recognize that open markets and international cooperation are essential for its success. The bioeconomy relies on access to diverse markets, technologies, and resources, as well as collaboration among countries and stakeholders. To that end, more work on globally acknowledged standards for the bioeconomy will be needed. Only by aligning the efforts towards common goals, policymakers, stakeholders, and actors within the bioeconomy can foster synergies that maximize the transformative benefits of this emerging field.

Key policies underscore the imperative for a skilled workforce in emerging and innovative bioeconomy sectors. Specific capacity-building programs are proposed to equip individuals with the necessary knowledge and skills for effective contributions to the bioeconomy.

Notably, biosafety and biosecurity aspects are rapidly gaining prominence in global bioeconomy policy frameworks, reflecting the growing importance of ensuring safety and security in bio-based activities.

Growing and changing science focus

Bioeconomy policies exhibit diverse approaches to technological development. While some strategies prioritize the ground-breaking new technologies, others focus on adapting existing technologies to suit local conditions. This distinction is particularly notable in emerging economies and developing countries, where the aim is to address ongoing societal challenges and promote rapid change. For instance, some developing countries may prioritize the adoption of biorefineries to harness locally available biomass resources, thereby creating

contemporary sustainable solutions for energy, agriculture, and other key sectors.

Another significant trend identified in the analysis of policy and strategy developments is the integration of AI with bioeconomy related research, resulting in the emergence of innovative forms of bioengineering and biomanufacturing. This convergence of AI and microbiology / cell biology opens new possibilities for the bioeconomy, enabling advancements in various sectors. These technologies are especially promoted to advance the health sector by developing personalized medicine, disease diagnostics, and drug discovery through AI-driven approaches applied to microbiological research. Additionally, they play a vital role in complex circular economy models by optimizing resource utilization, waste management, and recycling through microbiological processes.

Furthermore, the integration of AI with microbiology is expected to increase productivity in biomass production. By harnessing AI-powered tools and precision agriculture techniques, crop yields can be enhanced, the resource allocation can be better optimized, and food production can be expanded to non-arable land. This has the potential to increase biomass production and therefore support the growth of sustainable bio-based industries.

Many analyzed bioeconomy strategies recognize the necessity of addressing regional biomass gaps. This involves implementing a combination of advanced circular economy models to generate higher value from existing biomass and increasing agricultural, forestry, and maritime production and productivity to expand the overall supply. Moreover, the new bioeconomy strategies of China and the United States give greater importance to advancements in agricultural productivity, while the strategies within the European Union focus more on developing circular economy models.

A key strategic question for the future could be to better understand the synergies between the two development paths and design a shared and coordinated model that efficiently combines the strengths of both. Approaches for such a development already form an integral part in the current strategy documents.

Overall, both the new East African and Colombian bioeconomy strategies highlight the proactive approach taken by countries at different stages of national development to thoroughly analyze their strengths, weaknesses, and advance bioeconomy concepts tailored to their specific potentials and needs. East African states are focusing on practical innovations and basic developments, particularly in the agriculture and energy sectors. Both strategies seek to leverage their countries' abundant natural resources and biodiversity to solve local problems and access international markets. Building upon existing institutions and knowledge, Colombia promotes a high-tech bioeconomy model that, in some respects, is comparable to the US and China bioeconomy models.

Challenges to bioeconomy development

The commercialization and scaling up of the bioeconomy poses ongoing challenges that requires strategic solutions. While suggestions for tax reductions or direct subsidies exist, they are not the primary approaches embraced by the strategies analyzed. Instead, a prevalent trend focuses on reducing transaction costs throughout the supply chain as well as in legislative and trade processes. This is achieved through innovative proposals such as establishing bio-based resource stock exchanges, implementing quality standards and sustainability certifications, establishing data sharing infrastructures, and enhancing property rights. The development of sub-national bioeconomies is associated with the potential to generate technological and social innovations based on local resources and native knowledge, thereby creating more jobs and equitable value across economic sectors.

In summary, the strategies examined in this report have been developed through political processes within their respective countries and international regions. The active participation

of the private sector in technological and economic development of the bioeconomy is crucial for realizing the envisioned transitions outlined in the strategy documents. Without significant breakthroughs and investments in the bioeconomy, the transitions will not materialize, or they may not progress at a pace necessary to achieve various sustainability goals in time, particularly climate neutrality. At the same time, it is crucial to establish a robust and transparent regulatory framework to support and guide these innovations and investments. Such a framework is essential for promoting inclusive and sustainable development and receiving necessary public support. It ensures that the bioeconomy operates within a framework of responsible practices and regulations, which will lead to long-term viability and positive outcomes for the whole of society. Enhanced international cooperation and knowledge exchange remain paramount in achieving these goals. Governance aspects emerged prominently as well, as exemplified by China, EAC, and the participatory approach in Austria.

The report presented here is an exploratory endeavour. It is important to acknowledge that the results we have obtained are preliminary in nature. Given the complexity and dynamics of the global bioeconomy, attempting to provide an exhaustive analysis goes beyond the scope of this report. However, through our analysis we have been able to identify initial trends that offer valuable insights. The ongoing development and potential impacts of these trends present an exciting avenue for future research, inviting further exploration and investigation. Delving deeper into the robustness and implications of these trends holds great promise for advancing our understanding of the bioeconomy and its future trajectory.

Annex

Table 1: Official Dedicated Bioeconomy Policy Documents (since 2020)

Country/Region	Policy Level	Document Type	Name	Year
Australia	Sub-National	Roadmap and action plan (update)	Queensland Biofutures: 10-Year Roadmap and Action Plan	2022
Austria	National	Action plan	Aktionsplan Bioökonomie (in German)	2022
Brazil	Sub-National	Policy strategy	Plano Estadual de Bioeconomia do Pará: PlanBio Pará (in Spanish)	2022
China	National	Policy strategy	14th Five-Year Plan for Bioeconomy Development (in Chinese)	2022
Colombia	National	Policy strategy	Bioeconomía: para una Colombia Potencia viva y diversa: Hacia una sociedad impulsada po el Conocimiento (in Spanish)	2020
East Africa	Regional International	Policy strategy (summary)	The Eastern African Regional Bioeconomy Strategy: A summary	2020
		Policy strategy	The East African Regional Bioeconomy Strategy 2021/22 - 2031/32	2022
EU	Regional International	Progress report	EU Bioeconomy Strategy Progress Report	2022
Finland	National	Policy strategy (update)	The Finnish Bioeconomy Strategy: Sustainably towards higher value added	2022
Germany	Sub-National	Policy strategy	REVIERKOMPASS: Neue Wege für Innovation und Wertschöpfung	2022
	Sub-National	Policy strategy	Bioökonomie als Treiber für Wertschöpfung und Innovation: Strategiepapier zur Schlüsselrolle des Landes Sachsen-Anhalt bei der Etablierung einer Modellregion der Bioökonomie im Mitteldeutschen Revier (in German)	2021
Ireland	National	Action plan	Bioeconomy Action Plan 2023-2025	2023
Portugal	National	Action plan	Plano de Ação para a Bioeconomia Sustentável – Horizonte 2025	2021
US[60]	National	Executive Order	Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy	2022
		Report, White House Office of Science and Technology Policy	Bold goals for U.S. biotechnology and biomanufacturing: Harnessing research and development to future societal goals	2023

[60] Additional pertinent US bioeconomy policy documents not extensively discussed in this report:

- Report to the President: Biomanufacturing to Advance the Bioeconomy (December 2022)
- Bioeconomy Lexicon (December 2022)
- Developing a National Measure of the Economic Contributions of the Bioeconomy (March 2023)
- Bold Goals for U.S. Biotechnology and Biomanufacturing (March 2023)
- Ambiguities, Gaps, Uncertainties in Regulation of Biotechnology (March 2023)
- Building the Bioworkforce of the Future (June 2023)
- The Coordinated Framework for Regulation of Biotechnology: Plain Language Information on the Biotechnology Regulatory System (November 2023)
- Vision, Needs, and Proposed Actions for Data for the Bioeconomy Initiative (December 2023)