Food and Agriculture Organization of the United Nations

BIOECONOMY

# SUSTAINABLE AND CIRCULAR BIOECONOMY IN THE CLIMATE AGENDA

*OPPORTUNITIES TO TRANSFORM AGRIFOOD SYSTEMS*

Required citation:

**Gomez San Juan, M., Harnett, S. and Albinelli, I.** 2022. *Sustainable and circular bioeconomy in the climate agenda: Opportunities to transform agrifood systems*. Rome, FAO. https://doi.org/10.4060/cc2668en



ISBN 978-92-5-137092-6


## Aim of the paper

This paper offers a concise overview of how bioeconomy can contribute to the climate action strategies outlined in Intergovernmental Panel on Climate Change (IPCC) recommendations and nationally determined contributions[i] (NDCs) and adaptation strategies.[ii] As such, it is a valuable addition to the global stocktake exercise taking place on the implementation of the Paris Agreement, as well as to the FAO Strategy on Climate Change 2022-2031[iii] and the FAO Science and Innovation Strategy.[iv]

Specifically, the paper aims to:

1. provide decision-makers with examples of bioeconomy innovations that can support climate change mitigation and adaptation commitments; and

2. raise general awareness on bioeconomy as part of the FAO and global agenda for climate action under the different sectors of agrifood systems and bio-based industries.

## Key messages

- The bioeconomy – an economy based on the sustainable and circular use of biological resources and processes to produce food, feed, bio-based products and services – has major untapped potential to support both climate change mitigation and adaptation.

- Around one-third[v] of global greenhouse gas (GHG) emissions currently come from agrifood systems.[1] The bioeconomy offers opportunities to reduce GHG emissions along the agrifood system by replacing fossil-based resources and processes with biological ones, from microbiome innovations, biofertilizers and biopesticides, to new food sources, bio-based plastics and textiles, and biological waste management, to name just a few.[vi]

- A sustainable and circular bioeconomy also presents opportunities to improve climate change adaptation and resilience, through promoting ecosystem restoration and nutrient and water retention in soils, supporting indigenous and local livelihoods based on biological products and services, and building the conditions for more sustainably managed forests and fisheries.

- More than 60 countries and regions now have bioeconomy or bioscience-related strategies which, among objectives such as increasing food and energy security, supporting livelihoods and incomes, and fostering innovations, contribute to their efforts to meet their nationally determined contributions (NDCs) to cut GHG emissions and adapt to climate change.

- Several countries have identified circular bioeconomy as a strategy to achieve their NDCs, some have included bioeconomy practices in their climate agenda, and others explicitly include bioeconomy strategies and policies as key elements in their pathway towards Paris Agreement targets.

- With the FAO Strategic Framework 2022–31,[vii] FAO is the first United Nations entity to make bioeconomy a strategic priority. Indeed, in their Global Forum for Food and Agriculture communiqué from 2015, more than 60 ministers of agriculture advocated that FAO should take the lead on global bioeconomy policy development to help bring about more sustainable agrifood systems.

- Policymakers at local, national, regional and global level should pay urgent attention to how the bioeconomy could shape the climate path going forward – the resource-efficient circular bioeconomy alone is projected to reach a value of USD 7.7 trillion in 2030 (WBCSD, 2020), and it is important that the right structures are put in place at all levels so that bioeconomy development supports climate action and the achievement of the Sustainable Development Goals (SDGs).

- The transition to a sustainable and circular bioeconomy involves challenges and risks as well as benefits and opportunities. While the bioeconomy offers many potential solutions for climate action, any potential trade-offs involved in choosing one policy option over another (e.g. regarding land use, food security, human health and safety, etc.) should be carefully considered and mitigating measures put in place.

- FAO works with countries to improve policy coherence in order to achieve national sustainability objectives; for example, supporting the establishment of interministerial working groups for bioeconomy.

- Climate action is specifically referenced as a key criterion in the *Aspirational principles and criteria for a sustainable bioeconomy*,[viii] produced by the FAO-led International Sustainable Bioeconomy Working Group (ISBWG).

[1] For FAO, an agrifood system is a system including "food and non-food products that serves the production, processing, trade, marketing, consumption and disposal of goods that originate from agriculture, forestry, or fisheries. It also includes the inputs needed and outputs generated at each of these processes."

# 1

# What is bioeconomy and why is it relevant to climate action?

The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, microorganisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: terrestrial and marine ecosystems and the services they provide; primary production sectors that use and produce biological resources (crop and livestock production, forestry, fisheries and aquaculture); and all sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services (chemical and plastics industry, construction, pharmaceutical industry, textile industry, waste management and biotechnology).

Thanks to its cross-cutting nature, sustainable and circular bioeconomy provides a comprehensive approach to addressing several interlinked global challenges, including hunger and poverty, biodiversity loss, and climate change, in line with the Sustainable Development Goals (SDGs), the Paris Agreement and other Multilateral Environmental Agreements. Mainstreaming solutions for climate change mitigation and adaptation across farmlands, forests, grasslands, aquatic environments, bio-based industry and waste management into bioeconomy strategies will be an important step towards national and regional low-carbon, non-polluting growth strategies.

Currently more than 60 countries and regions (and growing) have bioeconomy and bioscience-related strategies.[ix] This includes countries in most regions globally.

While no bioeconomy strategy is the same, each one includes elements relating to sustainability and climate action.

The need to pursue climate change mitigation and adaptation is explicitly referenced as criterion 2.2 under Principle 2 ("Sustainable bioeconomy should ensure that natural resources are conserved, protected and enhanced") of the *Aspirational principles and criteria for a sustainable bioeconomy*, produced by the FAO-led International Sustainable Bioeconomy Working Group. Bioeconomy has also been identified as a key entry point to support south-south and triangular cooperation efforts to achieve the aims of the Paris Agreement and the SDGs.[x]

With the FAO Strategic Framework 2022–31, FAO is the first United Nations entity to make bioeconomy a strategic priority. Indeed, in their Global Forum for Food and Agriculture communiqué from 2015, more than 60 ministers of agriculture advocated that FAO should take the lead on global bioeconomy policy development to help bring about more sustainable agrifood systems.

Bioeconomy is a leapfrogging approach that offers enormous potential to deliver a truly innovative economic model whereby fossil-based resources (such as oil and gas, conventional plastics, synthetic fabrics, concrete) are replaced by biological alternatives.

Given the urgency with which climate action is needed, and the potential climatic and environmental benefits associated with

a sustainable and circular bioeconomy, it is unsurprising that bioeconomy is now attracting the interest of innovators and investors the world over. The resource-efficient circular bioeconomy alone – excluding food and feed end use – is projected to reach a value of USD 7.7 trillion in 2030 (WBCSD, 2020). Green finance is one of the leading factors propelling this phenomenon. For instance, the Green Climate Fund's Amazon Bioeconomy Fund project aims to reduce greenhouse gas emissions and increase climate resilience by promoting a paradigm shift to a bioeconomy in the Amazon region in six countries: Brazil, Colombia, Ecuador, Guyana, Peru, and Suriname. Meanwhile, in Europe, the first dedicated bioeconomy fund, the European Circular Bioeconomy Fund (ECBF), with EUR 100 million in backing from the European Union, aims to speed up investments in bio-based industries and innovations that harness the potential of renewable biological resources to sustainably meet our needs for food, materials and energy.

Moving forward, as more countries and regions adopt bioeconomy strategies, bioeconomy frameworks are likely to become increasingly important as solution providers in discussions around major global challenges including climate change, biodiversity loss, ecosystem degradation, and hunger and malnutrition.

## Box 1: How FAO supports climate action

In 2017, the Koronivia Joint Work on Agriculture (KJWA) decision was adopted under the United Nations Framework Convention on Climate Change (UNFCCC). The Koronivia decision addresses six interrelated topics on soils, nutrient use, water, livestock, methods for assessing adaptation, and the socio-economic and food security dimensions of climate change across the agricultural sectors. The decision resonates with FAO's core mandate to eliminate hunger, food insecurity and malnutrition, reduce rural poverty, and make agriculture, forestry and fisheries more productive and sustainable. FAO leverages the KJWA and other frameworks to support countries by providing technical support to adapt to and mitigate climate change through webinars, workshops and knowledge products. FAO also supports countries to catalyse investments that contribute to transforming agrifood systems, making them more efficient, inclusive, resilient and sustainable.

FAO supports its Members in these efforts by offering technical guidance, data and tools for improved decision-making and the implementation of mitigation and adaptation measures. The Organization's assistance to countries includes improving policy coherence in order to achieve national sustainability objectives; for example, supporting the establishment of interministerial working groups for bioeconomy. FAO also develops and disseminates tools and guidelines to assist countries in enhancing transparency in their national inventory reports, analysing the impacts of climate change, planning appropriate responses to these impacts and meeting reporting requirements. It facilitates the design of National Adaptation Plans (NAPs) and supports the development of nationally determined contributions (NDCs). FAO also increases awareness of countries on scaling up climate action in agrifood systems, as well as supporting investment mobilization in agriculture.

Beyond primary production, agrifood systems can contribute to a more sustainable bioeconomy. FAO supports sustainable agrifood systems transformation on the ground through its Bioeconomy for Sustainable Food and Agriculture programme and its Strategy on Climate Change 2022-2031, which highlights the importance of biomass, biological cycles, biological processes and biological diversity for climate action. Mainstreaming bioeconomy in Subsidiary Body for Scientific and Technological Advice (SBSTA) and climate change "Conference of the Parties" (COP) negotiations is now key for increased implementation of climate action commitments, such as those covered in KJWA discussions.

# 2

# How is sustainable and circular bioeconomy addressed in the global climate agenda?

The bioeconomy offers a holistic and cross-sectoral approach with high potential to contribute to climate change mitigation in several ways.[xi] Opportunities abound to reduce anthropogenic greenhouse gas (GHG) emissions not only through substituting fossil-based feedstocks, inputs and products with bio-based ones, but also through storing carbon in bio-based products, and through sequestering carbon dioxide ($CO_2$) from the atmosphere in biomass through plants and microorganisms (Nova Institute, 2021).

Bioeconomy also offers many adaptation benefits, such as a circular use of bioresources across agrifood systems, and supports biodiversity conservation and sustainable use, ecosystem restoration, and efficient and resilient new value chains that are flexible to uncertain climate events and potential market disruptions.

Sustainable and circular bioeconomy involves the use of biological science, technology and innovation for the sustainable production and use of biological resources, with the aim of achieving resource-use efficiency and circularity while promoting environmental and social benefits for the society. This is also recognized in global high-level fora such as the G7 Berlin Roadmap on Resource Efficiency and Circular Economy.

The Intergovernmental Panel on Climate Change (IPCC) affirms with high confidence that "sustainable agriculture and forestry, technology innovation in bio-based production within a circular economy and international cooperation and governance of global trade in products to reflect and disincentivize their environmental and social externalities, can provide mitigation and adaptation via bioeconomy development that responds to the needs and perspectives of multiple stakeholders to achieve outcomes that maximize synergies while limiting trade-offs" (IPCC, 2022; p. 2093).[xii]

## What is FAO's role in supporting bioeconomy policy development for climate action?

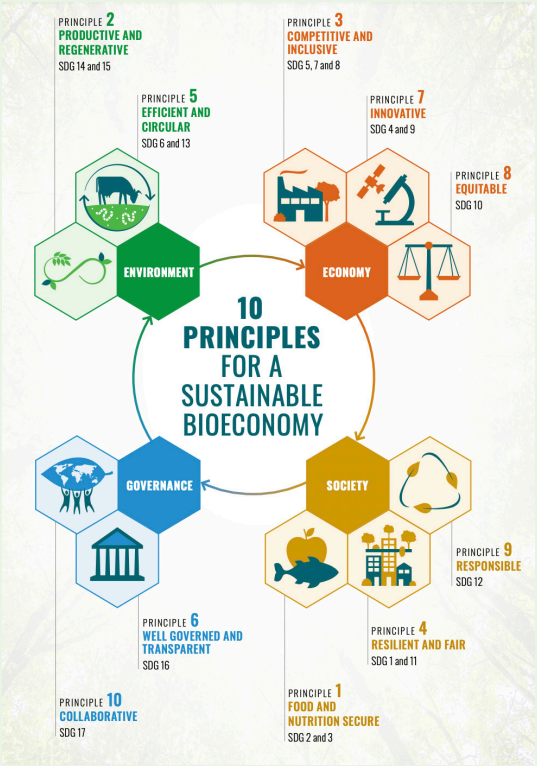
In the Global Forum for Food and Agriculture communiqué from 2015, it was recommended that FAO should take the lead on global policy discussions on sustainable and circular bioeconomy in food and agriculture. This led to the creation of FAO's Towards Sustainable Bioeconomy Guidelines project – supported by the Government of Germany – and the formation of the FAO-led International Sustainable Bioeconomy Working Group.

Now, FAO is moving towards a more strategic approach to bioeconomy with its Bioeconomy for Sustainable Food and Agriculture programme priority area, part of the better environment pillar of the FAO Strategic Framework 2022–31. Through this dedicated bioeconomy programme, FAO will work with countries to improve the sustainability of agrifood systems with bioeconomy solutions at three levels: technological, organizational and social. FAO works in pilot countries to support the identification of sustainable and circular opportunities to harness biological resources, including related knowledge, science, technology, and innovation. This work is underpinned by FAO's guiding documents, including the FAO Science and Innovation Strategy, and the FAO Strategy on Climate Change 2022-2031, which specifically references bioeconomy and highlights the importance of biomass, biological cycles, biological processes and biological diversity for climate action.

## Box 2: Aspirational principles and criteria for sustainable bioeconomy

Climate action is specifically referenced as a key criterion in the *Aspirational principles and criteria for a sustainable bioeconomy*, produced by the FAO-led International Sustainable Bioeconomy Working Group (ISBWG).

**Figure**: 10 Principles for a sustainable bioeconomy




Source: **FAO.** 2021. *Aspirational Principles and Criteria for a Sustainable Bioeconomy.* Rome. https://www.fao.org/documents/card/en/c/cb3706en/

Under Criterion 2.2, "Climate change mitigation and adaptation are pursued", the ISBWG states: "There is global agreement that it is imperative to adapt to and mitigate climate change. Bioeconomy is in a unique position to significantly contribute to climate change mitigation and adaptation through the replacement of fossil fuel-based goods with low-carbon bioproducts and the sustainable and circular management of resources. In that context, bioeconomy plays a crucial role to achieve national and international climate targets."

Other ISBWG principles and criteria also contribute to low-carbon efforts in agrifood systems, such as criterion 1.4 (food safety), principle 2 (conserve, protect and enhance biodiversity in bioeconomy activities), principle 4 (resilience), and principle 5 (circular economy and increased efficiency). Climate action is often an objective of bioeconomy strategies, as laid out in a series of case studies documented by FAO in the publication *Towards sustainable bioeconomy – Lessons learned from case studies*.[a]

[a] **FAO**. 2019. *Towards sustainable bioeconomy – Lessons learned from case studies*. Rome. https://www.fao.org/documents/card/en/c/ca4352en

## The need for a new development model outlined in NDCs

As of July 2021, all 191 Parties to the Paris Agreement had provided information in their NDCs on "mitigation targets and mitigation resulting from adaptation actions and/or economic diversification plans. The mitigation targets range from economy-wide absolute emission reduction targets to strategies, plans and actions for low-emission development."[xiii]

It is clear from the NDCs that Parties recognize the necessity of moving beyond a business-as-usual fossil-based development model to one that favours low-emission development to achieve large-scale GHG reduction targets. Agrifood systems, responsible for an estimated one-third of global GHG emissions, will have to do their part in contributing to these mitigation efforts. Within this context, a sustainable and circular bioeconomy based upon responsible consumption and production (SDG 12) offers tantalizing new opportunities for substituting fossil-based with renewable biological resources.

However, for beneficial transformation to occur, "the implementation of most conditional elements depends on access to enhanced financial resources, technology transfer and technical cooperation, and capacity-building support; availability of market-based mechanisms; and absorptive capacity of forests and other ecosystems."[xiii] From crop and animal production to forestry and fisheries, along the agrifood value chain to responsible processing, distribution, consumption and disposal, the sustainable and circular bioeconomy offers many innovative solutions with the potential to lower our carbon footprint while meeting multiple other goals (see Section 3 – Bioeconomy innovations supporting climate change mitigation and adaptation).

Many countries are mentioning and including bioeconomy practices as part of their agricultural mitigation[xiv] and adaptation strategies in their new or updated NDCs. For example, 91 out of 148 countries (61 percent) explicitly referred to soil organic carbon measures, many of which indicate bioeconomy practices such as soil organic amendments or integrated soil fertility management as mitigation and/or adaptation means (see Box 3 – National bioeconomy strategies and the NDCs).

## Box 3: National bioeconomy strategies and the NDCs

Several countries have identified circular bioeconomy as a strategy to achieve their NDCs, shedding light on the important role of the bioeconomy in the climate action. Ten countries have included bioeconomy practices in their climate agenda: Brazil, El Salvador, India, Mauritania, Namibia, Nigeria, Pakistan, Rwanda, Tunisia and Venezuela (Bolivarian Republic of).

Here are just a few examples of bioeconomy-related commitments in NDCs:

- The Bolivarian Republic of Venezuela focuses on the substitution of agricultural chemicals with bio-inputs, such as biocontrollers and biofertilizers, and on the use of biomaterials (wood, bamboo, bahareque) in construction (NDC 2021 – para 10.2.3 and 11.3.4).

- Pakistan and El Salvador harness biological control methods to keep pest populations under control, protect soil fertility and improve productivity, while encouraging investments in bioproduct industries (Pakistan Updated NDC 2021 – para 5.3 and 6.1; El Salvador Updated NDC 2021– annex 2).

- Canada, Colombia, Costa Rica and New Zealand explicitly include bioeconomy strategies and policies as key elements in their pathway towards Paris Agreement targets. Canada is currently exploring new opportunities for emission reduction through the bioeconomy in the British Columbia Province (Canada NDC 2021 - Annex 2). Colombia recognizes in its NDC the value provided by the bioeconomy for the protection of water, ecosystems and biodiversity (Colombia NDC 2020 – para 1).

- According to the upcoming New Zealand Bioeconomy Strategy, moving towards a circular bioeconomy is "essential to meeting emission budgets and 2050 targets", while at the same time delivering many co-benefits such as job opportunities, innovation and waste reduction (Aotearoa New Zealand First Emission Reduction Plan 2022 – Chapter 9).

- Costa Rica harnesses bioeconomy for the "sustainable production of high added value in all its regions and emerging bio-cities, based on the fair and equitable use of its biodiversity, the circular use of biomass and the country's biotechnological progress as a knowledge society". (Costa Rica NDC 2020 – para 15.3).

## Bioeconomy can support adaptation co-benefits within NDCs

When it comes to meeting adaptation goals within NDCs, bioeconomy for sustainable food and agriculture could also address many of the challenges that countries identify as priorities, from food production and nutrition security, water resource management, preservation and restoration of terrestrial and aquatic ecosystems, equitable economic development, and poverty reduction and support for livelihoods.

To name a few examples of how bioeconomy could help in addressing such challenges:

- Bioeconomy supports the sustainable development of tree-based systems (including agroforestry), which are essential for adaptation actions, income diversification and risk reduction. Indeed, as highlighted by FAO's recent publicationon on The State of the World's Forests (SOFO) 2022,[xv] many countries recognize the mitigation potential of forests in their recent nationally determined contributions. Many also recognize the role of trees in climate-change adaptation, and there is further potential for countries to integrate forests and trees into their national adaptation plans. The report identifies forestry as a key sector to build green value chains and enable a transition towards a more circular use of resources.

- Bioeconomy considers new food sources (such as seaweed, microalgae, edible insects, cell culture-based food products, plant-based protein alternatives and 3-D printed food), which could offer game-changing potential to bolster food and nutrition security, while requiring less water, less energy and fewer chemical inputs.

- Using biological solutions such as biofertilizers, biopesticides and bioremediation can help restore ecosystems so that they can store more carbon and become more productive and resilient in the face of extreme weather events and, indeed, in a context of energy and chemical input shortages.


## How is FAO supporting countries in implementing their NDCs?

FAO, as the leading source of technical expertise on sustainable agricultural development, has the tools, experience and expertise required to support countries in all five of these areas. Moreover, sustainable and circular bioeconomy is ideally suited as an overarching framework to ensure successful interventions in these areas.

When it comes to supporting countries in implementing their NDCs,[xvi] FAO has identified five priority areas for interventions in food and agriculture:

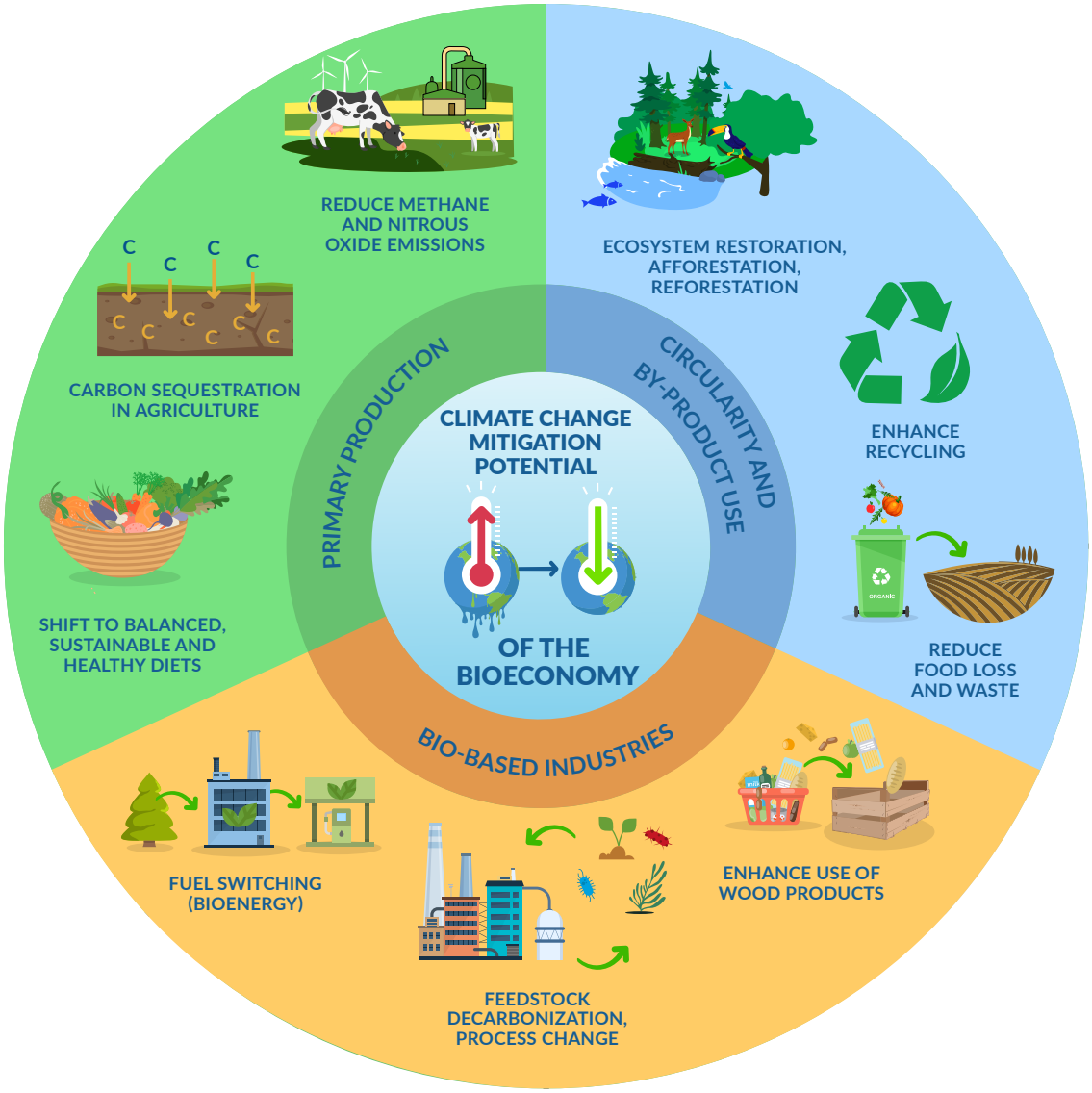
1. Enhanced framework transparency.
2. Coherent policy frameworks.
3. Research, analysis and tools.
4. Capacity development in agriculture.
5. Mobilizing investment for agriculture.

## Bioeconomy and climate change mitigation

The executive summary of the Working Group III (WGIII)[xvii] contribution to the IPCC's Sixth Assessment Report (AR6) recommends several promising options for mitigating greenhouse gas emissions. In this regard, sustainable bioeconomy offers many practices and innovations that have the potential to contribute to and enhance many of these mitigation options.

This paper shows how bioeconomy examples can effectively contribute to some IPCC mitigation options, drawing a link between bioeconomy and climate change mitigation. Nine bioeconomy examples have been chosen in three main macrosectors that relate to agrifood systems: primary production (agriculture, forestry and other land use (AFOLU) and fisheries); bio-based industries; and circularity and by-product use.

**Figure 1.** IPCC mitigation options that bioeconomy can support along the whole agrifood system




Source: Authors' own elaboration.

**Table 1:** Nine IPCC mitigation options and the corresponding bioeconomy innovations

| Macrosectors | IPCC mitigation options | Bioeconomy innovations |
|---|---|---|
| Primary production | Shift to balanced, sustainable healthy diets | New food sources |
| | Carbon sequestration in agriculture | Microbiome innovations |
| | Reduce methane and nitrous oxide emissions | Biofertilizers |
| Circularity and by-product use | Ecosystem restoration, afforestation, reforestation | Biopesticides |
| | Enhance recycling | Bio-based biodegradable plastics |
| | Reduce food loss and waste | Residue management and cascading use |
| Bio-based industries | Enhance use of wood products | Enhance use of wood products |
| | Feedstock decarbonization, process change | Natural organisms and enzymes in food production and processing |
| | Fuel switching (bioenergy) | Sustainable bioenergy from waste |

Source: Authors' own elaboration.

## Bioeconomy and climate change adaptation

In terms of climate change adaptation, Working Group II (WGII)[xviii] to AR6 finds with a high degree of confidence that "integrated, multisectoral solutions that address social inequities, differentiate responses based on climate risk and cut across systems, increase the feasibility and effectiveness of adaptation in multiple sectors".

Sustainable and circular bioeconomy provides exactly the type of cross-cutting, integrated and multisectoral framework necessary to address the finding of WGII. It promotes the use of biological resources, processes and innovations to help transform agrifood systems so that they are more efficient, inclusive, resilient and sustainable, while supporting the development of a fair and green economy and ensuring all global citizens have access to enough nutritious food. Indeed, the sustainable and circular bioeconomy framework aligns climate change mitigation and adaptation, biodiversity preservation and ecosystem restoration with a human-centred approach that simultaneously seeks to promote food security and nutrition, social equity, and economic opportunities (especially for women, youth, Indigenous and marginalized groups), as well as responsible consumption and production.

This link between climate resilient development and bioeconomy is exemplified in the draft Namibia Bioeconomy Strategy 2023–2028, which was developed by Namibia's National Commission for Research, Science and Technology (NCRST), with the support of FAO. The strategy aims to harness the potential of Namibia's biological resources as a means of moving away from fossil-derived resources; enhance circularity of biological residue streams; promote food security and nutrition; and facilitate sustainable and inclusive development that benefits society as a whole.

# 3

# Bioeconomy innovations supporting climate change mitigation and adaptation

The following are examples of innovations within the bioeconomy that support climate change mitigation and adaptation goals, while also contributing to other societal goals such as improved food security and nutrition, enhanced environmental stewardship, better waste management and green economic development opportunities.

## Shift to balanced, sustainable and healthy diets

### BIOECONOMY INNOVATION

#### New food sources

New food sources and production systems (NFPS) range from fermentation-derived ingredients (microalgae and mycoproteins), seaweed, and edible insects, to cultivated meat, seafood and dairy, and plant-based protein alternatives. Some of these "new" foods are already in diets in different countries and regions, boosting nutrition and providing livelihoods to people. They are also used to produce more sustainable sources of feed.

Sustainable consumption and behavioural change should be paired with sustainable production and adapted to local conditions, including through citizen participation in agrifood systems transformation.

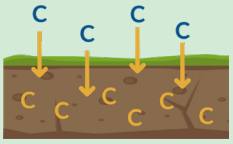
The bioeconomy framework can help look at the benefits and opportunities as well as the challenges and risks of new food sources, using an integrated framework focusing on topics including climate and environment, food security and nutrition, food safety, and livelihood opportunities for small-scale food producers.

### EXAMPLE

#### Potential of new food sources for reducing GHG emissions

Microbial proteins, plant-based proteins, marine-based proteins, insect-based proteins and cell-based food are included under the European Union's Food 2030 research and innovation framework for their potential contribution to a climate-friendly and sustainable dietary shift by 2030.[xix]

In addition to climate mitigation gains, new food sources could reduce pressure on forests and land used for feed, support the preservation of biodiversity and planetary health, and contribute to preventing forms of malnutrition in developing countries.




## Carbon sequestration in agriculture

**BIOECONOMY INNOVATION**

### Microbiome innovations

The term microbiome refers to a community of microorganisms – including bacteria, fungi, algae, viruses and other microbes – that live and interact together in a defined environment. Examples of microbiomes include the networks of soil microorganisms that determine the fertility status of a soil ecosystem, the microorganisms that carry out vital functions in plants and animals, and the communities of microorganisms that impact human nutrition and health. Microbiome science, technology and innovation is a fast-growing part of the bioeconomy showing exciting potential to provide sustainable solutions and applications for agrifood systems. Specifically with regard to climate and the environment, there is increasing evidence that the soil microbiome plays a pivotal role in ecosystem health, agroecosystems and the climate system.

**EXAMPLE**

### Crop production, soil microbiome and climate change

A major review by FAO[xx] has for the first time made a direct link between crop production, the soil microbiome and climate change impacts. Drawing on evidence from more than 2 000 scientific publications, the review provides solid, scientific evidence of strong connections between certain crop production practices – such as use of organic fertilizers, reduced tillage, increased on-farm plant diversity, and plant variety selection – and a healthy soil microbiome that can improve the ability of soils to store carbon, retain water and nutrients, and support plant growth and health. To unlock these benefits at a mass level, the review recommends: bolstering public support for research, development and innovation; leveraging education and communication; supporting commercialization of microbiome innovations; and developing regulatory tools to ensure that microbiome innovations are safe, effective, affordable and accessible to all.

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Soil microbiome diversity is fundamental in ensuring the delivery of a wide range of ecosystem services, including provisioning of clean water and air, food and raw materials, recreational space and biodiversity.

The soil microbiome is involved in the planet's climate system as it regulates terrestrial greenhouse gas fluxes and soil carbon dynamics.

## Reduce methane and nitrous oxide emissions

| BIOECONOMY INNOVATION | EXAMPLE |
|---|---|

### Biofertilizers

Biofertilizers are living microbes, such as bacteria or fungi, which enhance plant nutrition by either fixing atmospheric nitrogen or mobilizing and increasing nutrient availability in soils and in plants. Moreover, biofertilizers may generate additional mitigation by indirectly reducing synthetic fertilizer manufacturing requirements and associated emissions. Biofertilizers have also shown important results in reducing methane emissions ($CH_4$) from rice cultivation and increasing yields.[xxi]

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Rice fields treated with the Azolla biofertilizer can give the same yields as those treated with chemical nitrogen fertilizers.

### Methane and nitrogen dioxide reductions due to biofertilizers

The use of efficient microorganisms as growth promoters has been implemented by FAO as a soil fertilization alternative in many countries and biophysical conditions. Microorganisms improve the efficiency of the use of organic matter by plants. They also increase phosphorus solubility and nitrogen (N) fixation in the soil, e.g. arbuscular mycorrhizae and rhizobacteria. In addition, they can reduce the emissions of GHGs by up to 10 kg $CO_2$ equivalent per kg mineral N replaced. Azolla and phosphobacteria are a kind of blue-green algae used as microbial inoculants in soils and can bring about a significant reduction in methane emissions. However, policy is key to raise awareness of the benefits of biofertilizers. For example, Argentina's Ministry of Agriculture, Livestock and Fisheries has an Advisory Committee on Bio-inputs for Agricultural Use, which advises authorities on regulations in relation to bio-inputs and gives its opinion on their implementation. Meanwhile, at the provincial level, policy supports the creation of biofactories, which are centres for the development and production of different biopreparations.[xxii]

## Ecosystem restoration, afforestation, reforestation

**BIOECONOMY INNOVATION**

### Biopesticides and biological control

Land degradation, decreasing water resources, loss of biodiversity, and excessive use of synthetic fertilizers and pesticides are some of the environmental challenges that influence preparedness to adapt to climate change. The use of arthropod biological control and biopesticides – which include living microorganisms, biochemicals derived from natural resources and plant-based extracts – has been scientifically demonstrated to be often just as effective as chemical pesticides, but with the added benefit of being much safer for human and environmental health. Additionally, the use of biocontrol and biopesticides can help avert the emission of GHGs associated with synthetic pesticide manufacturing, distribution and application.

**EXAMPLE**

### Biopesticides, biocontrol and integrated pest management

FAO promotes the use of biocontrol and biopesticides within the framework of integrated pest management (IPM), in fighting pests such as fall armyworm and desert locust. The use of biocontrol, biopesticides and agroecological practices through an IPM programme has the potential to reduce synthetic pesticide use by at least 70 percent in tropical Asia while maintaining yield production. This level of pesticide reduction would translate to an annual reduction of 170 000–180 000 tonnes of carbon equivalent in countries such as Viet Nam or Indonesia.[xxiii]

FAO in the desert locust crisis.

Aircraft spraying biopesticides to combat a desert locust outbreak in East Africa.

©FAO/Michael Tewelde

## Enhance recycling

**BIOECONOMY INNOVATION**

### Bio-based biodegradable plastics

A scenario calculation by the European Environment Agency (2021) estimated that substituting all fossil-based plastics in the European Union with bio-based alternatives would result in an annual GHG emissions reduction of 30 percent. This comes with the caveat that bio-based plastics should be examined on a case-by-case basis, particularly in regard to trade-offs associated with land use, food security, environmental impacts, waste flows, etc. There also needs to be infrastructure for end-of-life biodegradability and compostability, to follow the principles of circular end-of-life. A separate study by the Organisation for Economic Cooperation and Development (OECD) noted that bio-based plastics could provide adaptation co-benefits through potentially generating greater numbers of jobs than biofuels.[xxiv]

**EXAMPLE**

### Bio-based plastics made from agave in Mexico

In Mexico, by-products from the cultivation and processing of the agave plant have been used to make bio-based plastics for items such as beverage packaging and vehicle components. Replacing fossil-based plastics with agave-based plastics has helped reduce the carbon impact of these items. Agave-based plastics have also provided adaptation co-benefits such as providing Mexican farmers with income-diversifying options.[xxv]

Agave harvesting produces large amounts of residues, which come from both the agave plantations and liquor production process. Within bioeconomy, these residues become a valuable input for bio-based plastics.

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## Reduce food loss and waste

| BIOECONOMY INNOVATION | EXAMPLE |
|---|---|

### Residue management and cascading use

The full exploitation of organic streams represents a valuable resource in the circular and sustainable bioeconomy. Discarded food can be turned into beneficial products such as biomaterials, biochemicals, biopharmaceuticals, and bioenergy. By reusing such bio-based residues, we can help reduce wasteful practices and improve nutrient recycling and valorize all types of biomass. This contributes to responsible food consumption and production, to reduce pressure and competition on resources and land, which supports food security and nutrition and has significant potential to reduce GHG emissions through agrifood systems.

### Textiles from pineapple residues

Many companies are developing innovative plant-based textiles that replace synthetic or unsustainably produced textiles. For example, an alternative to leather is being made from pineapple leaf fibres. These fibres are the by-product of the pineapple harvest, meaning that no extra land, water, fertilizers or pesticides are required to produce them. In some countries, such as the Philippines, the first step in the processing of the fibre is carried out by local women cooperatives, which provides the women additional income, while creating new opportunities related to pineapple growing.

In some countries local cooperatives produce fibres from pineapple leaves through decortication (extraction of biomass fibres). The final textile product is recyclable and compostable.

## Enhance use of wood products

**BIOECONOMY INNOVATION** | **EXAMPLE**

### Enhance use of wood products

The use of wood products refers to the fate of harvested wood for material uses and includes two distinctly different components affecting the carbon cycle, comprising carbon storage in wood products and material substitution. Bioeconomy harnesses the use of wood and wood by-products in different industries and stages of the production chain. There is strong evidence at product level that wood products are associated with lower GHG emissions over their entire life cycle when compared to products made from non-renewable or emissions-intensive materials, such as steel or concrete.

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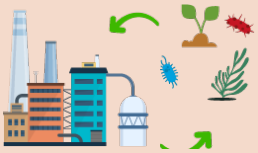
### The New European Bauhaus

The European Commission's New European Bauhaus is an interdisciplinary initiative that calls for a transformative path towards sustainable living spaces in urban and rural development. A European Parliament report stresses the importance of transforming, upgrading and retrofitting the existing building stock by applying nature-based solutions such as wood and reducing waste and increasing durability, reusability and circularity in the built environment. Under the New European Bauhaus initiative, the European wood-based sector has launched Wood4Bauhaus, an open platform for collaboration and knowledge-sharing aiming at encouraging research and innovation in innovative use of wood in the built environment.

Wood was also at the heart of several international calls to action during and after COP 26 in Glasgow in late 2021. The publication *Growing our low-carbon future: time for timber* sets out the climate benefits of deploying timber, rather than concrete and steel, and proposes a plan that policymakers should adopt to help keep carbon emissions within 1.5 °C.

Using wood products in construction displaces the use of carbon intensive alternatives such as steel, concrete and plastics.



## Feedstock decarbonization, process change

**BIOECONOMY INNOVATION**

### Natural organisms and enzymes in food production and processing

Industries are already shifting to more bio-based low-carbon pathways, for example through feedstock decarbonization, use of biomass, and change of polluting processes to bio-based and biotechnology processes. The enzyme industry is one of the most promising in the bioeconomy. Bioeconomy harnesses research and development of bacteria and enzymes that can be used in processing pathways to increase efficiency of the biotechnology processes, reducing energy consumption and GHG emissions. Natural organisms or enzymes are currently used in several processes within a number of industries, such as in the food industry and other industries that use raw materials derived from living organisms as key production inputs, e.g. pulp and paper, leather and textile industries. Enzymes and other biological organisms can perform industrial processes with significantly less energy, without the use of aggressive chemicals and with less waste, compared with traditional manufacturing systems. Industrial biotechnology can thus result in a more efficient use of natural resources and reduced energy consumption.

**EXAMPLE**

#### Potential GHG emission reductions with enzymes and natural organisms

GHG emission reductions can be achieved by industrial biotechnology, using enzymes and natural organisms. According to the OECD, industrial biotechnology and bio-based products have a mitigation potential of 1–2.5 billion tonnes of $CO_2$equivalent per year, by 2030. Several countries are investing in developing and enhancing bio-based industries. In 2018, the United States Department of Agriculture expanded the BioPreferred Program, with the aim of increasing the development, purchase, and use of bio-based products. Moreover, the Japan Bioeconomy Strategy, launched in 2019, focuses particularly on industrial biotechnological developments, often in connection with artificial intelligence or technological applications.

Natural organisms and enzymes can perform industrial processes with significantly less energy, chemical inputs and waste, compared to traditional manufacturing systems.

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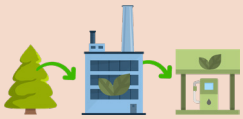

## Fuel switching (bioenergy)

| BIOECONOMY INNOVATION | EXAMPLE |
|---|---|

### Sustainable bioenergy from residues

Sustainable modern bioenergy systems are closely linked with food security and energy security. Indeed, agrifood systems and forestry are the main source of bioenergy feedstock. Bioenergy can be sustainably produced using agrifood residues, including by-products and wastewater, while delivering several benefits. The use of biomass from agricultural or food residues guarantees high resource efficiency, since it does not require additional land or inputs. In terms of GHG emission reductions, sustainable bioenergy can contribute to replacing the consumption of fossil fuels in the energy mix, while avoiding the practice of burning residues. Moreover, bioenergy can be co-produced together with fertilizer and soil health improvers, providing adaptation co-benefits related to ecosystem resilience.

### Bioenergy production as a tool for waste management

Taking into consideration the principles of cascading use of biomass, where biomass uses are prioritized in terms of their value and use, biomass from agricultural and industrial residues has an important role to play in replacing fossil-derived energy with energy from bio-based feedstock. An example is anaerobic digestion of agricultural and livestock residues, which can reduce methane emissions and produce bioelectricity. Waste management also includes wastewater treatment. For instance, microalgae are used to remove pollutants from wastewater, capturing atmospheric $CO_2$ acting as a carbon sink. Contextually, microalgae biomass can be used to produce biohydrogen and biomethane. By-products can be further employed to extract high value compounds and ultimately used as fertilizer. Bioenergy from agrifood waste can also deliver important adaptation co-benefits, such as creating opportunities for additional income for famers, while providing them with energy self-sufficiency.

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Spirulina production in Central African Republic.

Microalgae spirulina, besides playing an essential role in food security, is an important carbon sink and ultimately its biomass can be employed for biofuel production.

# Concluding points

- While further research and comprehensive and comparable data are needed to estimate the full potential of the bioeconomy to support climate change mitigation and adaptation objectives, some bioeconomy practices, bioproducts or bio-innovations in different sectors have already shown promise in terms of their potential to reduce GHGs and support climate resilience. Building further science-based knowledge around successful and valuable examples can increase confidence in the potential of these technologies to support climate action.

- To achieve net zero emissions, society should employ a combination of three mechanisms within the circular bioeconomy; using new renewable biological resources; improving efficiency of biomass already used by current activities (through enhanced lifetimes of products, cascading use of biomass, recycling); and rescuing atmospheric carbon and storing it in soils, forests, aquatic environments, and bioproducts.

- This paper provides a concise overview of how bioeconomy fits into the climate action strategies outlined in IPCC recommendations and NDCs and adaptation strategies. As such, it aims to enrich discussions around more ambitious climate action within the framework of the global stocktake exercise, a core part of the Paris Agreement.

- Soil carbon sequestration and nutrient management have great potential for both climate change mitigation and adaptation – e.g. soil microbiome improvements or biofertilizer use can help increase soil organic matter in cropland and restore deteriorated soil, improving carbon sequestration and increasing food security.

- Sustainable bioeconomy encourages the shift to healthier and lower emissions diets, contributing at the same time to assuring food security.

- Bioeconomy science, technology and innovation harnesses the knowledge-intensive use of biotechnology and biomass in the sustainable production and management of goods, services and energy, with the aim of achieving resource-use efficiency and circularity. International scientists have called for a greater integration of bioeconomy in global climate action, since its cross-sectoral nature makes it essential, yet often overlooked, in mitigation and adaptation policies.[xxvi]

- A growing number of FAO Members have bioeconomy or bioscience-related strategies where agrifood systems are key contributors to sustainable growth that mitigates and adapts to climate change. Embedding a sustainable and circular bioeconomy framework more deeply in the climate change agenda would help both contribute to climate action, and provide innovative climate-smart solutions to tackle other global challenges, including hunger and malnutrition, poverty, biodiversity loss, and environmental degradation.

- Bioeconomy has a big role to play in tackling climate and planetary crises. To make optimum use of this role, several mechanisms should be implemented at the same time: investment in innovations, replacing fossil fuels, sharing knowledge and analysis of trade-offs, capacity building across all sectors to bring about a green economy, and harnessing the potential of responsible consumption, circular use of biomass and more responsible production and trade.

- Global climate action should move beyond sectoral approaches and upscale the technologies that can bring win-win benefits to society and the planet. The bioeconomy framework can be a valuable tool for the analysis of trade-offs among sustainable use of resources. Biotechnology development and bio-innovations should be used in a way that helps tackle current crises and minimizes sustainability tradeoffs.

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Sustainable and circular bioeconomy can play a major role in supporting climate change mitigation and adaptation and in increasing climate resilience. This paper offers examples of how bioeconomy policies, practices and innovations can help countries in achieving their climate change-related commitments, while highlighting the importance of bioeconomy for agrifood systems transformation.

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The authors are grateful for the essential contributions of Adrian Leip (Bioeconomy, Head of Sector - European Commission), Ana Kojakovic, Energy and Natural Resources Expert (FAO), and Buyung Hadi, Agricultural Officer (FAO). Design is by Candida Villa-Lobos.

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CC2668EN/1/11.22