



## Review Article

## Addressing the ecological sustainability through bio-economy - A comprehensive review

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## ARTICLE INFO

## Article history:

Received 23-10-2024

Accepted 27-11-2024

Available online 09-01-2025

## Keywords:

Bioeconomy

Sustainable development

Bioresources

energy sources

Bioassessment

## ABSTRACT

In addition to providing a cross-cutting viewpoint on the social shift away from the non-renewable economy and towards long-term sustainability, the bioeconomy propels the advancement of life science and biotechnology as a blueprint for the future evolution of human society. The creation, utilization, preservation, and regeneration of biological resources to offer long-term solutions is known as the bioeconomy. It may generate food, energy, and industrial products using renewable resources such as plants, animals, and microbes. The bioeconomy may worsen already-existing social tensions and inequalities, resulting in environmental and social instability and eventually biodiversity loss, if resources, opportunities, and rewards are not distributed fairly. Biotechnology, agriculture, and forestry are some of the industries that make up the bioeconomy.

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## 1. Introduction

The sustainable utilization of renewable biological resources to create a more economically and environmentally sustainable future is the subject of the new idea known as the "bioeconomy".<sup>1</sup> The necessity to address resource limitations and advancements in microbiology is driving this global movement.<sup>2</sup> The fundamental idea or theory behind the bioeconomy is the sustainable use of renewable biological resources to support both ecological sustainability and economic growth (Figure 1). This involves moving away from an economy that depends on fossil fuels and toward one that depends on resources like forestry, biotechnology, and agricultural products. It presents chances for agriculture and industry, including the development of new employment and financial prospects. Utilizing naturally regenerated resources like crops, forests, and microorganisms—which are regarded as sustainable substitutes for finite fossil fuels—is the core of the

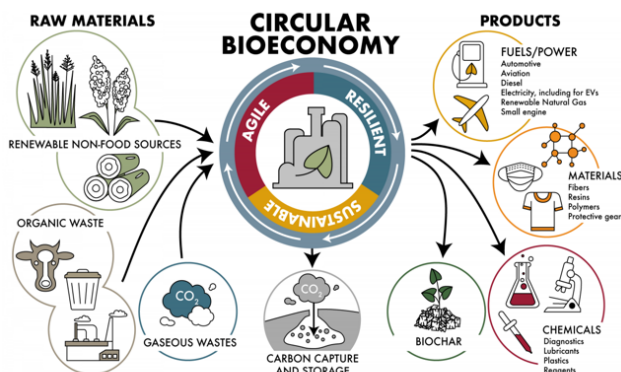
bioeconomy.<sup>3,4</sup> Furthermore, the sustainable bioeconomy initiatives align with the Sustainable Development Goals of the United Nations and are increasingly serving as the focal point for achieving these goals.<sup>5</sup>

The term "bio-based economy" was initially used to describe the bioeconomy in the United States' "Developing and Promoting Biobased Products and Bioenergy" strategy. According to the organization for Economic Co-operation and Development's 2004 report on Biotechnology for Sustainable Growth and Development, the bioeconomy is "an economy that uses renewable biological resources, efficient biological processes, and ecological industrial clusters to produce sustainable bio-based products, thus creating jobs and incomes." The popularity of the bioeconomy increased as a result.<sup>6</sup> Later, the EU published a report that defined the bioeconomy as a knowledge-based bioeconomy that uses knowledge from life sciences to create new, competitive, sustainable, and ecologically efficient products that can help future societies move away from relying exclusively on fossil fuels for industrial

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feedstocks and energy.<sup>7</sup> Furthermore, in a report titled "The National Bioeconomy Blueprint," the US government views the bioeconomy as an economic model that leverages bioscience research and innovation to provide economic activity and public welfare advantages.<sup>8</sup>



**Figure 1:** How the bioeconomy sustains people and the planet.

Source: <https://asm.org/ASM/media/Microcosm/2024/Spring/circular-economy-illustrated-1200x680.png>

To improve sustainability at the social, ecological, and economic levels and make the shift to a bioeconomy, strategies and policies are being developed.<sup>9</sup> It is still essential to comprehend how the bioeconomy affects public policy in practice. By developing a theoretical model that synthesizes diverse viewpoints within the bioeconomy and offers insights for decision-making processes, especially in the context of public policy formulation, this work seeks to make a contribution. A sophisticated grasp of the bioeconomy's conceptual development and cross-sectional boundaries is necessary due to its dynamic character.<sup>10</sup> This article intends to give policymakers a thorough grasp of the dynamics of the bioeconomy and make it easier to create evidence-based policies that support sustainable development by outlining these elements within the theoretical model. This comprehensive review aims to close this gap and give policymakers a useful tool for well-informed decision-making by creating a theoretical model that clarifies the intricacies of the bioeconomy and its implications for decision-making.

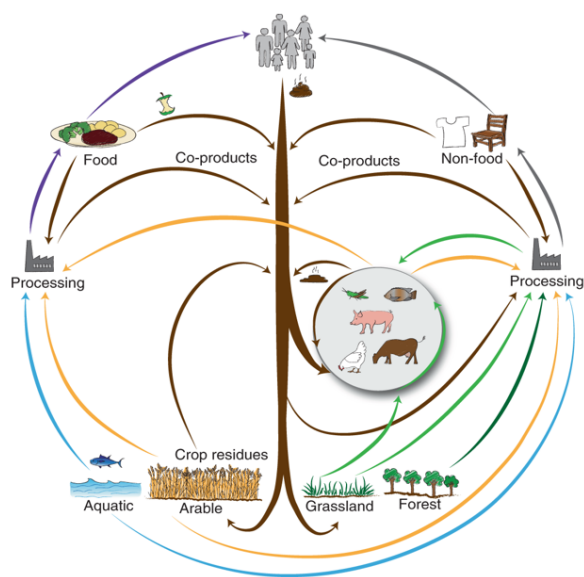
## 2. Discussion

The need to shift to a carbon-neutral bioeconomy is growing as a result of climate change. To encourage research, funding, and public support, a comprehensive set of policies will be needed. The 21st century's primary priority in all cultures is how to decrease the usage of

non-renewable resources while enhancing human living standards sustainably through economic development. It is encouraging that more than 50 countries, including the India, United States, China, South Africa, and the European Union, have agreed to implement sustainable bioeconomy-based strategies powered by cutting-edge life sciences and biotechnology-related research and development.<sup>11</sup> Current studies suggest that, over the next three decades, around 1–2 trillion USD in annual worldwide investments would be needed for agriculture, green chemicals, biofuels, bioenergy, and biotechnology services. According to Kircher,<sup>12</sup> this represents 1.3 percent to 2.6 percent of the globe's gross domestic product. Moreover as per "The 14th Five-Year Plan for Bioeconomy Development," which was recently unveiled by the Chinese government, the bioeconomy is "centered on the safeguarding, expansion, and exploitation of biological resources, to drive forward the advancement of biological sciences and the field of biotechnology while providing an overall strategy for the long-term growth of human society".

A key component of bioeconomy is the dedication to ecological sustainability, which aims to minimize greenhouse gas emissions, minimize environmental damage, and encourage responsible land and resource management.<sup>13,14</sup> In order to improve resource usage efficiency and spur innovation and competitiveness, the bioeconomy depends on technological developments in biotechnology, genetic engineering, and other scientific fields.<sup>15,16</sup> The bioeconomy's cross-sectoral spread includes the production of food and feed, biofuels, biogas, bioplastics, and biomaterials, as well as sectors such as agriculture, energy, and materials.<sup>17,18</sup> The fundamental idea highlights the possibility of resolving resource shortages, lessening the impact on the environment, and generating long-term economic prospects through a sustainable biomass flow (Figure 2). Achieving a balance between environmental responsibility and economic growth, however, is a dynamic and changing topic with a variety of interpretations, approaches, and ongoing conversations.<sup>3</sup> In conclusion, sustainability, eco-efficiency, and the bioeconomy all aim to improve efficiency and lessen their negative effects on the environment, but they do it from various angles and with different priorities.

On the flip side there are drawbacks to the bioeconomy as well, namely the requirement to strike a balance between environmental sustainability and economic growth and guarantee a fair distribution of advantages.<sup>19</sup> Ethics, such as those pertaining to genetic manipulation, animal husbandry, and the fair distribution of benefits, are essential because of the dependence on biological resources.<sup>20,21</sup> Despite receiving governmental attention, the bioeconomy has not been widely adopted.<sup>21</sup> Although earlier transitions, like the switch from wood to coal and coal to oil, took several decades, they did so before the temporal restrictions



**Figure 2:** Biomass flows in a circular bioeconomy.

Source: Muscat, A., de Olde, E.M., Ripoll-Bosch, R. et al. Principles, drivers and opportunities of a circular bioeconomy. *Nat Food* 2, 561–566 (2021). <https://doi.org/10.1038/s43016-021-00340-7>

imposed by the rapidly changing climate. Therefore, immediate, and decisive policy measures are required due to the urgency of the bioeconomy transformation. Unexpectedly, there is still disagreement around the definition, scope, and key drivers of the bioeconomy idea. According to Bracco et al.<sup>22</sup> there are at least three primary narratives: one that emphasizes replacing carbon from fossil fuels, another that is propelled by biotechnology, and a third that aims to maximize the use of biomass in an environmentally sustainable way.

There are about fifty countries having national bioeconomy strategies or policies that support the growth of a bioeconomy, including all of the nations that make up the G7. Concerns about climate change, declining biodiversity, resource depletion, the security of food and clean water, and the availability of energy are the primary motivators behind the idea. Although these problems call for various answers, they are all related to the necessity of moving away from fossil fuels and toward a more sustainable carbon cycle in society. The difficulty of balancing supply-side and demand-side measures across several sectors, including waste management, forestry, agriculture, industrial manufacturing, and marine resources, is faced by every new policy. Here, we show how crucial a systemic approach is to the creation of policies for the shift to a bioeconomy.

Credible standards for the broad sustainability objectives that serve as the central theme of the many narratives are another facet of managing the bioeconomy transition. In

order to reduce anticipated national rivalry, demand-side policies are especially reliant on internationally accepted standards. To make it possible to track progress toward greater sustainability, we would support further efforts to harmonize policies pertaining to sustainability criteria and related best practice approaches. Increased sustainability is the main argument used by any government to support public involvement in the bioeconomy. However, it is completely predictable that the growing use of biomass for food, materials, and chemicals could result in over-exploitation of natural resources and undesirable outcomes like increased illegal logging, soil degradation, groundwater depletion, decreased biodiversity, and international disputes, even with the best of intentions to promote sustainability and resilience.

With the revitalization and prosperity of numerous primary and secondary industries, the bioeconomy is currently a leading concept at the governmental and industry levels that promises to strike a balance between economic development and social and environmental goals.<sup>5,23</sup> Generally speaking, the bioeconomy promotes using resources derived from living biomass in place of fossil fuels, and innovation and knowledge are key components that help make this shift. Nonetheless, policy and science have developed a number of definitions and interpretations of the bioeconomy.<sup>23–25</sup>

With varying focuses, a number of nations have implemented bioeconomy policies.<sup>23</sup> Although national strategies in Europe vary depending on the amount of biomass available domestically in each nation, they typically rely on the development and contribution of a broad range of industries and economic sectors, such as food, forestry, chemistry, pharmaceuticals, textiles, and others.<sup>26,27</sup> However, the United States' approach places a heavy emphasis on biotechnology and biofuels.<sup>23,28,29</sup> Overall, the commercial aspect of the bioeconomy is heavily emphasized in the global political debate, with environmental and social factors being incidental.<sup>30,31</sup> A more thorough description of the bioeconomy is gradually incorporating some environmental sustainability concepts. Among these are the cascading use of biomass and its environmentally and socially responsible procurement. The latter promotes resource reuse and recycling by giving high-value biomass uses precedence over energy usage, based on the circular economy's waste hierarchy principle.<sup>32,33</sup>

At times researchers have made insightful observations about the bioeconomy and its conflicts with natural capital as well as other ecological and environmental factors<sup>34–36</sup> (Hetemäki et al. 2017, Marchetti et al. 2015, Székács, 2017). Palahí et al.<sup>37</sup> (2020) have recently promoted a circular bioeconomy based on biodiversity, with integrated solutions that allow for fair and inclusive changes to metropolitan areas, industrial sectors, and land-food-health systems. Individuals or groups of beneficiaries' historical,

geographic, and socioeconomic circumstances influence ecosystem services.<sup>38</sup> Thus, ecosystems are governed in accordance with the fundamental principles that civilization wishes to uphold. Synergies or trade-offs between diverse ecosystem services and between sustainability aspects (economic, societal, and environmental goals) are inevitable outcomes of the implicit decisions that underlie different forms of ecosystem management.<sup>39,40</sup>

Therefore, it is crucial that bioeconomy policies produce the intended results and impacts. The policy debate above emphasizes the value of systems thinking while simultaneously highlighting the necessity of experimenting, which is consistent with transition theory. We have offered a generic policy matrix as a transition management toolbox, trying to include the temporal features of value chain maturation that are applicable to a wide range of renewable carbon value chains.



**Figure 3:** Need of sustainable and circular bioeconomy  
Source: [https://www.iberdrola.com/documents/20125/1227826/Bioeconomy\\_Sustainable\\_Circular\\_EN.jpg](https://www.iberdrola.com/documents/20125/1227826/Bioeconomy_Sustainable_Circular_EN.jpg)

### 3. Conclusion

The future development of technologies that manipulate biology depends on practitioners, policy makers, and consumers acknowledging that biology is a technology in itself. Decision-making in biological technology requires considering the best available facts and risk factors. Governments should enhance market accessibility, stimulate demand, manage access to biological genetic resources, increase intellectual property protection, and promote the transformation of intellectual property in everyday applications. Financial resources should be fully utilized and supported for bio-innovations. Countries worldwide will promote the innovative bioeconomy by improving bio-risk control, prevention, and governance, accelerating

healthcare, bio-agriculture, bio-energy, environmental protection, and bio-informatics. The four main sectors driving the bioeconomy's growth are biomedicine, bio-agriculture, bio-manufacturing, and bio-security. Three avenues for industrial growth, biotechnological innovation, and government policy assistance will contribute to the bioeconomy's improved development in the next ten years. Distinguishing between technology errors and carelessness is crucial when assessing the effects of poor decision-making and creating laws or rules to increase safety. Nearly all of the major issues confronting humanity today have a connection to climate change, and the bioeconomy offers answers to them. It can lessen hydric stress and provide food security. In order to prevent overexploitation, it will support sustainable management of natural resources. Additionally, there will be less reliance on fossil fuels and increased support for renewable energy sources.

By lowering greenhouse gas emissions and enhancing public health, the bioeconomy will aid in the development of policies targeted at climate change adaptation and mitigation. Additionally, it will support the creation of green jobs while preserving competitiveness and productivity. On the whole, nevertheless, we don't know much about how the research communities of ecosystem services and bioeconomy interact. The bioeconomy has presented obstacles as well as new chances for economic growth, job creation, and innovation. Dependency on provisioning services, particularly biomass, but also genetic resources and information-based ecosystem services (such as biosecurity, bioprospecting, and cultural services linked to scientific and educational advancement) are characteristics of the bioeconomy in general (Figure 3). Therefore, the supply of (different) ecosystem services is essential to all bioeconomy concepts, and the management of land and resources influences the supply. Given that many ecosystem services are co-produced, bioeconomy visions, plans, and actions truly inform the management of socio-ecological systems.

### 4. Source of Funding

None.

### 5. Conflict of Interest

None.

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**Cite this article:** Dubey S. Addressing the ecological sustainability through bio-economy - A comprehensive review. *J Pharm Biol Sci* 2024;12(2):95-99.