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POTENTIAL FOR BIOECONOMY DEVELOPMENT IN THE ALTO SOLIMÕES-AMAZONAS-BRAZIL MICROREGION

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Magno dos Santos[1], Rosimery Menezes Frisso[2], Guilherme Martinez Freire[3], Jânderson Rocha Garcez[4], Vonin da Silva e Silva[5], Nicolas Andretti de Souza Neves[6] and Graciella Martignago[7].

ABSTRACT

The bioeconomy is a strategic alternative for sustainable development, especially in a scenario of climate change and increased demand for natural resources. The transition to a sustainable bioeconomy requires a balance between economic growth, environmental protection, and social inclusion, with the participation of various actors. Thus, this work focuses on analyzing the potential for development of the bioeconomy in the microregion of Alto Solimões, located in the State of Amazonas, Brazil. The study aims to identify the opportunities, challenges and existing natural resources that can boost sustainable

[1] Master in Business Development and Innovation
Federal Institute of Education, Science and Technology of Amazonas
E-mail: magno.santos@ifam.edu.br
ORCID: https://orcid.org/0009-0009-5649-8729
LATTES: https://lattes.cnpq.br/1233853794018453
[2] Master in Aquaculture
Brazilian Micro and Small Business Support Service
E-mail: frisso_zootecnia@hotmail
ORCID: https://orcid.org/0009-0009-7620-6199
LATTES: https://lattes.cnpq.br/6669602987850266
[3] Master in Fisheries Sciences
Federal University of Amazonas
E-mail: Gmfreire@gmail.com
ORCID: https://orcid.org/0000-0002-6880-2339
LATTES: http://lattes.cnpq.br/7874124349822874
[4] Dr. in Fisheries Resources and Fisheries Engineering
Federal Institute of Education, Science and Technology of Amazonas
Email: janderson.garcez@ifam.edu.br,
ORCID: https://orcid.org/0000-0001-8216-9501
LATTES: http://lattes.cnpq.br/6529230698034427
[5] Master in Agroecology
Federal Institute of Education, Science and Technology of Roraima
Email: voninifrr@gmail.com
ORCID: https://orcid.org/0000-0002-0428-9409
LATTES: http://lattes.cnpq.br/9162774396093046
[6] Master in Agricultural Education
Federal Institute of Education, Science and Technology of Amazonas
Email: nicolas@ifam.edu.br
LATTES: http://lattes.cnpq.br/1830435033188744
[7] Dr. in Business Administration
Miami University of Science and Technology
Email: graciella.martignago@mustedu.com
ORCID: https://orcid.org/0000-0003-0722-5061
LATTES: http://lattes.cnpq.br/2116155644461800

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economic activities, integrated with the conservation of biodiversity and the strengthening of local communities. For this, a qualitative research of exploratory and descriptive nature was developed. It was found that there is low socioeconomic development, but the micro-region has great potential for the bioeconomy due to its rich biodiversity and the traditional knowledge of native peoples, positioning itself as a strategic pole for the future of the bioeconomy in Brazil. However, it faces challenges such as a lack of infrastructure and complex logistics.

Keywords: Amazon. Circular economy. Sustainability.

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INTRODUCTION

In a global context of growing demand for natural resources and concern about climate change, the bioeconomy emerges as a strategic alternative to leverage sustainable development. Changes in weather patterns can affect water availability, energy production efficiency, and agricultural productivity, exacerbating existing challenges (Ngammuangtueng *et al*., 2023). In addition to stimulating technological innovation and valuing biodiversity, this model also strengthens local economies, generates green jobs, and promotes social inclusion.

The Amazon is a region characterized by intense contrasts and great diversity in socioeconomic, cultural, and political aspects. In recent decades, the region has faced a continuous increase in poverty and extreme poverty rates, in addition to the advance of production systems based on monoculture, which demand strict standards and promote the degradation and replacement of Amazonian ecosystems (Sousa *et al*., 2024).

The exploitation of natural resources, although it generates economic growth, does not contribute significantly to the improvement of the living conditions of local populations. Indicators such as the human development index, per capita income, and access to basic sanitation reveal high levels of poverty and inequality in the Brazilian Amazon (Rodrigues & Silva, 2023). The development model in the Amazon has reinforced inequalities by transforming forest ecosystems into tradable resources, often excluding local communities from the economic benefits generated (Ioris, 2016).

The Amazon region is diverse, composed of multiple geographical, ecological and social realities, which requires specific and adapted development strategies. However, public policies often ignore this diversity, treating the region as homogeneous. Natural wealth, such as biodiversity and river resources, has significant economic potential, but suffers from a lack of infrastructure, technological innovation, and sustainable management (Grisotti & Moran, 2020).

Damasceno, Souza, and Cavaliero (2022) cite that the region faces unique challenges due to its vast territorial extension, isolation of communities, and limitations of energy infrastructure, in need of innovative and sustainable solutions to meet the energy demand of communities and institutions.

The transition to a sustainable bioeconomy requires targeted efforts to balance economic growth, environmental protection, and social inclusion, with an emphasis on regional adaptations and active multi-stakeholder participation (Kleinschmit *et al*., 2025).

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While there are conflicts and contradictions in the paths to integrate biodiversity into bioeconomy strategies, there are also opportunities to promote a bioeconomy that values biodiversity (Queiroz-Stein *et al*., 2024).

In the micro-region of Alto Solimões, a potential for the development of the bioeconomy is expected, due to multifactors such as the vast biodiversity and the presence of an incipient innovation ecosystem, requiring investments and adjustments. By aligning economic growth with environmental preservation, the bioeconomy offers a pathway to a sustainable future, emphasizing the interconnectedness of economic, environmental, and social systems and promoting long-term resilience and well-being (Dietz *et al*., 2024).

Thus, the research aims to analyze the potential for development of the bioeconomy in the micro-region of Alto Solimões, in the State of Amazonas, Brazil, identifying the opportunities, challenges and available natural resources that can foster sustainable economic activities, aligned with the conservation of biodiversity and the strengthening of local communities. In addition, it seeks to propose strategies and public policies that can boost the bioeconomy in the region, contributing to socioeconomic development and environmental preservation.

METHODOLOGY

A qualitative research was developed (Merriam, 2002; Patton, 2015; Bhangu, Provost & Caduff, 2023), of an exploratory and descriptive nature, which is the initial process of the investigation and serves to seek more information in order to become familiar with the phenomenon or obtain a new perception of it (Cervo, Bervian & Silva, 2007) based on the hypothetical-deductive method.

Initially, a bibliographic research (Vergara, 1998) was presented, which consists of a study based on published material, such as books, theses and dissertations, scientific articles and legislation on the subject of bioeconomy. Then, data collection was carried out through bibliographic and documentary research. The most relevant works and documents on the subject were identified and selected. Then, a detailed reading of the chosen works was carried out, highlighting the main arguments and positions of authors and institutions. The information obtained was recorded on reading cards and organized by topics, in order to facilitate the analysis and comparison of the data.

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THEORETICAL FOUNDATION

BIOECONOMY: HISTORY, CURRENT PANORAMA AND PERSPECTIVES.

The bioeconomy arose from the need to harmonize economic development with environmental issues, based on the use of renewable natural resources linked to the application of biotechnologies.

The origin of this term dates back to the works of Nicholas Georgescu-Roegen, a Romanian economist and mathematician who explored the relationship between economics, natural resources, and the laws of thermodynamics through his works: **"**The Law of Entropy and the Economic Process" and "The economic process is irreversible and limited by the availability of natural resources, which requires a more efficient and conscious use of these resources" (Georgescu-Roegen, 1971). While Georgescu-Roegen did not use the word bioeconomy in the current sense, his analysis of sustainability may certainly have influenced the development of the concept.

The Organization for Economic Cooperation and Development-OECD (2009), in its report: "The Bioeconomy by 2030: Designing a Policy Agenda", defines the bioeconomy as an economy based on the use of renewable biological resources and advanced biotechnologies for the sustainable production of food, energy and materials.

According to Silva, Pereira and Martins (2018), there is still no consensus on the definition of bioeconomy and the definitions used by the various authors group both historical and more recent aspects. Mejias (2019) discusses definitions and the emergence of this term and states that it is a recent science and many researchers propose definitions and possible areas related to it. The same author proposes that the bioeconomy is a science that seeks economic development in a sustainable way that is compatible with economic growth.

Vivien *et al*. (2019) investigated the subject in depth and divided the bioeconomy into segments based on competing approaches among bioeconomy stakeholders, which they identified through their narratives, namely: Bioeconomy I: considering the limits of the biosphere; bioeconomy II: a science-based bioeconomy and Bioeconomy III: a bioeconomy based on biomass.

The Brazilian Forest Service (2024) reports that the concept of bioeconomy varies according to the approach of those who formulate it, but the predominant view is of an economy based on knowledge and the sustainable use of natural resources to develop products, processes, and services. This institution also proposes a definition, based on the

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forest bioeconomy, as activities related to the obtaining of forest products and forest ecosystem services produced in a sustainable way, considering the environmental, social and cultural aspects related to the use of forest resources.

The concept of bioeconomy has gained strength in political agendas since 2011, with emphasis on the European Union, the United States and recently Brazil.

In 2013, the European Parliament's Committee on the Environment, Public Health and Food Safety launched a motion for a resolution on innovation for sustainable growth: a bioeconomy for Europe. According to this document, the bioeconomy offers a unique opportunity to promote sustainable growth, while addressing challenges such as food security, resource scarcity and climate change (Legislative Observatory European Parliament, 2012).

In April 2012, the United States published a national bioeconomy project, detailing steps to better harness research innovations to address national challenges in health, food, energy, and the environment. The project supports investments in research and development in biotechnology, such as genetic engineering and bioinformatics, promoting new solutions in biofuels, agricultural production and health (House, 2012).

Brazil, although it has potential for the development of the bioeconomy, only began to regulate this topic as of 2022 with the complementary bill 150/2022 that proposes the institution of the National Bioeconomy Policy. The project defines guidelines for the development of the bioeconomy in Brazil, following the principles of sustainable development, the protector-recipient and the user pays, eco-efficiency, reasonableness and proportionality, prevention, precaution, citizen participation, and social control (BRASIL, 2022).

In a complementary way, there is Ordinance No. 3,717, of November 30, 2023, which establishes the national strategy for bioeconomy and sustainable regional development of the Ministry of Integration and Regional Development (MIDR, 2023). Also relevant is the action plan on science, technology and innovation in bioeconomy of the Ministry of Science, Technology, Innovation and Communications launched in 2018, which deals with the themes of biomass, biorefinery processing, bioproducts, the Brazilian Bioeconomy Observatory and the National Bioeconomy Committee (MCTI, 2018).

In 2024, the National Bioeconomy Strategy was instituted through Decree No. 12,044, of June 5, 2024, which aims to: promote sustainable development, value forest and

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socio-biodiversity economies, develop innovation ecosystems, and expand the insertion of bioeconomy products (BRASIL, 2024).

In the current context, the bioeconomy has been driven by advances in biotechnology, through the development of techniques such as genetic engineering, advanced bioprocesses that have allowed the creation of products from biomass, such as biofuels, bioplastics and pharmaceuticals, in addition to industrial innovation (Organization for Economic Cooperation and Development-OECD, 2009).

The bioeconomy is also influenced by traditional sustainable practices. In the Amazon, for example, traditional communities have historically used biodiversity in a sustainable way. Nobre (2023) suggests that the Amazon can be a bioeconomy hub based on its biodiversity due to the opportunity to integrate modern science and traditional knowledge, promoting a sustainable and inclusive economy.

Currently, the bioeconomy is considered a key strategy in facing challenges such as climate change, food security, and the transition to sustainable economies, and can be aligned with the UN Sustainable Development Goals (SDGs), promoting practices that integrate sustainability and innovation, reducing the need to use fossil resources, and promoting the circular economy. However, it faces challenges such as the need for integrated public policies and social inclusion, especially in underdeveloped and developing countries.

Authors such as Patermann and Aguilar (2018) highlight the importance of connecting science, technology, and public policies for the advancement of the bioeconomy. Braun (2018) emphasizes its role in food security and climate crisis mitigation. Bugge, Hansen, and Klitkou (2016) explore different approaches to the concept of bioeconomy, while Jain *et al*., (2022) discuss bioenergy and biowaste bioproducts and associated modern circular economy: current research trends, challenges, and future perspectives. These authors converge on the view that the bioeconomy is essential for a sustainable and equitable transition.

In terms of future prospects, Letizia *et al*., (2023), evaluated the prospects of the forest bioeconomy on a regional scale, focusing on environmental and social fields, and results identify gaps with potential for future development in topics such as ecosystem services, social acceptance of new forest products, and social life cycle analysis. The study also discusses policy implications, including the need for participatory approaches and

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economic incentives to support the implementation of sustainable practices in the forestry sector.

Queiroz-Stein and Siegel (2023) address the integration between bioeconomy and biodiversity as an opportunity to align economic, social, and environmental conservation objectives and cite as a challenge inadequate governance and exclusion of traditional communities that weaken the potential of the bioeconomy in many contexts. The same authors recommend greater participation of local actors, development of appropriate technologies and adoption of incentive policies to promote sustainability.

Tham *et al.,* (2023) present a comprehensive analysis on the use of microalgae as a sustainable alternative for feed production in the aquaculture sector, highlighting its importance in the context of the circular bioeconomy. The research addresses the role of microalgae in replacing traditional feed ingredients, such as fishmeal and soybeans, which have high environmental impact and sustainability limitations. Nagarajan *et al*., (2024) also presented a similar study in a review on the use of microalgae as a sustainable technology for food production in aquaculture, inserted in the context of the circular bioeconomy.

Cheah *et al*., (2023) studying the circular bioeconomy in the palm oil industry: current practices and future prospects, highlighted the importance of sustainable practices and the application of circular bioeconomy principles to mitigate environmental impacts and promote economic and social sustainability. These authors pose challenges to the technological and economic barriers that limit the adoption of large-scale circular bioeconomy practices, and understand that advances in waste management technologies, product diversification, and sustainable certifications can improve the industry's global reputation and increase its competitiveness.

Proestou and Feindt (2024) explore how different countries define and implement bioeconomy strategies, and highlight variations in approaches between the northern and southern hemispheres, considering the challenges and opportunities in integrating biodiversity and sustainable development. Countries in the northern hemisphere, such as Germany and Finland, focus on areas such as bioenergy, biotechnology and biomass processing, with less attention to biodiversity. In the Global South, bioeconomy strategies tend to include more stakeholders and recognize the economic value of biodiversity and ecosystem services.

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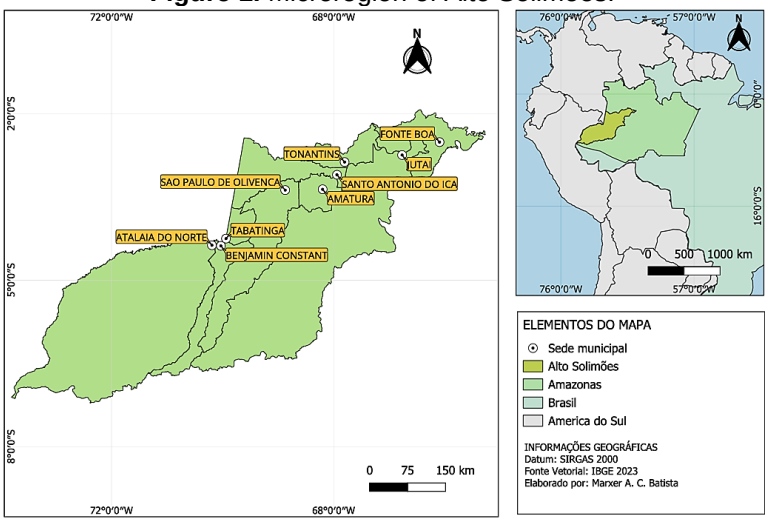
RESULTS AND DISCUSSION

POTENTIAL FOR DEVELOPMENT OF THE BIOECONOMY IN THE UPPER SOLIMÕES

The Microregion of Alto Solimões, located in the Southwest Mesoregion of the State of Amazonas, covers the municipalities of Amaturá, Atalaia do Norte, Benjamin Constant, Fonte Boa, Jutaí, Santo Antônio do Içá, São Paulo de Olivença, Tabatinga and Tonantins. Located near the Amazon triple border region (Brazil, Colombia and Peru), its total area is 213,281.24 km², corresponding to approximately 13.67% of the total area of the state, which is 1,559,168.117 km², as shown in figure 1 (Alto Solimões Observatory, 2024).

Figure 1. Microregion of Alto Solimões.



Source: Courtesy of Professor Marxer Antônio Colares Batista-IFAM, 2024.

Brazil's GDP per capita reached R$50,193.72 in 2023, a real increase of 2.2% compared to 2022. There is a large difference, the smallest (between R$ 30,406.41 and R$ 42,011.65) for the municipalities of Alto Solimões (IBGE, 2024). The HDI and schooling between 6 and 14 years old are also below the national average (AtlasBR, 2022). These indicators reflect the difficulties of the region, implying low development capacity in the traditional way. On the other hand, the low population density brings the advantages of availability of natural resources, opportunity for sustainable planning and better use of the territory.

The potential for bioeconomy development in the Alto Solimões is intrinsically related to the natural and cultural wealth of the region, marked by its unique biodiversity and the traditional practices of local communities. The region is a hotbed of potential pharmaceuticals, bioactives, and herbal medicines, as shown in a mapping of the

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commercialization of medicinal plants in the municipality of Benjamin Constant-AM (Dias & Araújo, 2024).

Melo (2023) reports on the use of medicinal plants by indigenous people, addressing aspects such as their social, economic, and cultural importance. The author highlights the social and economic viability, where medicinal plants are seen as an affordable alternative for treating diseases, especially in communities where access to conventional medicine is limited.

The Amazon region is home to a great diversity of native agricultural species, especially fruit trees. Non-predatory fruit extraction emerges as a promising alternative for regional development, integrating family labor and providing an important source of income (Marin & Coutinho, 2024).

The potential for the production of fruits that are still little known such as the macambo (*Theobroma Bicolo*) whose form of consumption can be fried or roasted seeds, seed porridge, seed broth, chocolate and can also be used in animal feed (Tello & Billacrês, 2022). Alves, Billacrês, and Rodrigues (2024) also verified 33 types of fruits sold in São Paulo de Olivença, including mapati (*Pourouma cecropiifolia*), uixi (*Endopleura uchi*), jambo (*Syzygium malaccense*), ingá açu (*Inga cinnamomea*), cajarana (*Spondias mombin*), apuruí (*Alibertia sorbilis*), and abil (*Pouteria caimito*). These species are still little commercially exploited.

In Tabatinga-AM, Ramos and Billacrês (2022) made a diagnosis of the fruit basket and among the 25 types of fruits, some peculiar to the region were identified, such as the Colombian marí (*Poraqueiba* sp.), marí brasileiro (*Poraqueiba* sp.), camu camu (*Myrciaria dubia*), bacurí (*Platonia insignis*) and rambutan (*Nephelium lappaceum*). These species also do not have an organized production and processing system like other domesticated fruit trees.

As a highlight, rambutan is a multifunctional fruit with potential for industrial use, meeting nutraceutical interests as it contains bioactive compounds such as geraniin, ellagic acid, and corilagine, which have antioxidant, anti-inflammatory, antidiabetic, and anticancer properties (Bhattacharjee & Chander, 2022). The husk and seed have a high concentration of antioxidants and are effective in combating oxidative stress and metabolic diseases (Bhattacharjee & Chander, 2022). In addition, several parts of the plant (fruit peel extract, seed and leaves) have antimicrobial activity against *Staphylococcus aureus, Candida* sp. *Pseudomonas aeruginosa,* among other microorganisms (Tsong *et al.,* 2021).

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Also in evidence, camu camu is a highly nutritious Amazonian fruit rich in bioactive compounds, including vitamin C, polyphenols, and carotenoids. Its antioxidant, antihyperglycemic, antihypertensive, and antiobesity properties are widely recognized. This fruit contains compounds such as anthocyanins (cyanidin-3-O-glucoside), flavonols (myricetin, quercetin), ellagic acid and proanthocyanidins. Biofunctional antioxidant, anti-inflammatory, and antiproliferative properties are also recognized – bark extracts have shown activity against tumor cells (Chacón, Loaiza, & Osorio, 2023).

In addition to the possibilities for plant exploration, the region has an abundant ichthyofauna (Garcez *et al*., 2022). Studying the productive aspects, obstacles and development of fish farming in the municipality of Benjamin Constant, Mota *et al*., (2021) found that the main species cultivated in this municipality were *Colossoma macropomum, Brycon amazonicus* and *Piaractus brachypomus.* The same authors also reported that the main challenges of the sector include the high cost of feed, difficulties in accessing the property, lack of maintenance of the facilities, absence of technical assistance, lack of environmental licensing, insufficiency of public policies aimed at the sector and the unfeasibility of commercialization outside the municipality.

In this micro-region, fishing still predominates, however, there is potential for the development of fish farming due to the great diversity of fish species and water availability. Fish farming has stood out as a promising economic alternative, however, most aquaculture enterprises in the region still operate in an amateur way. Although there is qualified labor, it is not adequately integrated into the labor market, in addition, the supply of inputs for fish farming in the region is quite limited (Garcez *et al*., 2021).

One of the main obstacles in the development of this region is logistics. In this sense, there is a project of the Ministry of Planning and Budget that aims at logistical and commercial integration in regions of difficult access. Thus, there is a plan for the upper Solimões region to benefit from the Amazon route, one of the five South American integration routes (BRASIL, 2025). This route will allow river flow from Manaus to Tumaco (Colombia), Esmeralda (Ecuador), Manta (Ecuador), Paita (Peru) and Chancay (Peru). This project stimulates the creation of direct and indirect jobs in the transport, logistics and trade sectors, promoting the valorization of production and adding value to the products produced in the region.

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FINAL CONSIDERATIONS

Alto Solimões is a micro-region of the State of Amazonas with a low level of economic and social development, but with great potential for income generation through the bioeconomy, thanks to the biodiversity present in its forests, rivers and the traditional knowledge of native peoples, consolidating the region as a strategic hub for the future of the bioeconomy in Brazil.

Despite the high potential, the development of the bioeconomy in Alto Solimões faces challenges such as the lack of infrastructure, difficulties in accessing credit and the need to harmonize economic practices with environmental preservation. Solving these barriers requires an integrated approach, involving government, the private sector, NGOs and local communities.

With structured and sustainable initiatives, the bioeconomy in Alto Solimões can become a development model that combines environmental conservation, social inclusion and technological innovation.

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