Hungarian University of Agriculture and Life Science

Bioeconomy Sectors in Latin America and Caribbean Countries: towards a sustainable development

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by

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LIST OF ABBREVIATIONS

LAC	Latin America and Caribbean
CEPAL/ ECLAC	Economic Commission for Latin America and the Caribbean
GDP	Gross Domestic Product
OECD	Organisation for Economic Cooperation and Development
SGDs	Sustainable Development Goals
GBS	Global Bioeconomy Summit
FAO	Food Agricultural Organization
VCR	Comparative Advantage
COVID	Coronavirus
MOI	Manufacturing output of the industrial source
MOA	Manufacturing output of agriculture source
GVA	Gross Value Added
LSCA	Life Sustainable Cycle Assessment

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1. INTRODUCTION

As a basic idea, the bioeconomy focuses on exploiting and managing natural resources from land, air, and sea to produce goods, services, and knowledge by combining scientific and technical advances without depleting resources for future generations.

One of the key goals of the bioeconomy is to reduce the dependence on fossil fuels and promote renewable energy (Hodson De Jaramillo et al., 2019a; Papadopoulou et al., 2021; Perišić et al., 2022). It also seeks to connect industries that use biological resources to produce bio-based products and services while improving product life cycles and creating new markets (European Commission, 2019; Dorokhina & Kharchenko, 2017).

It is also well known that the bioeconomy aligns with the majority of the United Nations' Sustainable Development Goals (SDGs) by addressing major global challenges such as population growth, rising demand for biomass, fossil fuel depletion, and climate change (Diemer et al., 2021; Heimann, 2019a; Linser & Lier, 2020). The SDG bioeconomy relationships can be bundled into ecological, industrial, and socio-economic dimensions.

Many countries, including France, Germany, the Netherlands, Finland, Japan, and Russia, have established bioeconomy strategies, and about 50 have included them in their policies (Global Bioeconomy Summit 2018, 2018; Iriarte, 2021). Developing countries are also using bioeconomy principles to enhance sustainable development and achieve commitments under the Paris Climate Agreement (Delzeit et al., 2021).

Based on the aforementioned notions, the current study's primary goal is to investigate the value of bioeconomy sectors in one of the richest biomass production regions, Latin America and the Caribbean (LAC). A bioeconomy model can promote industrial growth, value-added production, and economic development in the region due to its biodiversity, natural resources, and favourable climate (Boeri et al., 2020; Food and Agriculture Organization of the United Nations, 2018a; Interamerican Institute for Agriculture Cooperation, 2019; Rodriguez, 2017; Sasson & Malpica, 2018; Schröder et al., 2020).

Given the scarcity of studies that determine the regional importance of bioeconomy sectors in the region, this study aims to identify the main sectors, their economic importance, and the link between the various sustainable development goals that will drive this economic model in the region in the long run.

The region was chosen because the primary author of the study is from Ecuador. The author attempted to highlight the importance of the bioeconomy in LAC through a series of statistical analysis and case studies in various economic sectors that allow us to examine the region's reality, as well as its challenges and opportunities.

1.1. Research procedure

As a first step, we established as a research topic the study of the "Bioeconomy Sectors in Latin American and Caribbean Countries and their relationship with sustainable development," on which we determined the main questions that our research wants to answer around the established problem of the topic. The second phase consisted of an exhaustive bibliographic review, which is included in the second chapter of this thesis, allowing us to go deeper into the research topic. Figure 1 demonstrates the graphical interpretation of the research flow.

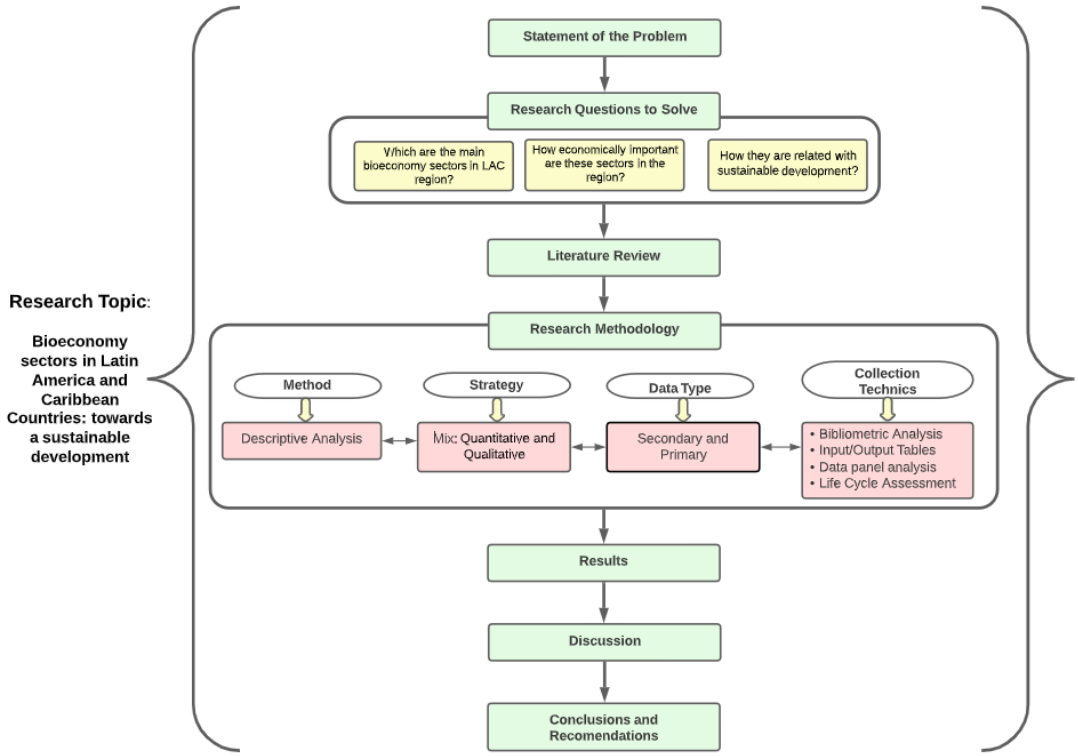

Figure 1. Research Flow Chart
Source: Authors own construction

The third part consisted of executing the entire methodological design of the research. As shown in the figure, we will use a descriptive method; the data to be analyzed will be quantitative and qualitative. Finally, the techniques of analysis of these data are detailed according to each subtopic to be treated, which allows us to answer the questions established for this research. The next stage consists of evaluating the results obtained from the data analysis and making our interpretation. This is linked with the discussion part, where we compare studies and research done in recent years that allow us to make assumptions from our results. Finally, in the last part of the dissertation, we will build the main conclusion and recommendation from all the results and discussion sections that will give us the final remarks and future directions of the research topic.

1.2. Problem to solve

The present study seeks to find answers to essential questions regarding the Bioeconomy in one of the most megadiverse areas, such as the Caribbean and Latin America. The research is focused on reviewing three relevant points: a) the main bioeconomy sectors developed in the region, b) the economic importance of these sectors, and finally, c) how sustainable those sectors are in different aspects.

Bioeconomy can provide opportunities and, in significant aspects, represents a necessity for Latin America and the Caribbean region (World Bank, 2020a). In the first case, it is seen as an opportunity because the region has the highest levels of biodiversity, productive landscapes, genetic resources, and the natural capacity to produce biomass. The region's vast biodiversity offers the potential for innovative products of added value for the bioeconomy (Ordoñez Olivo & Lakner, 2023). In addition to the above, the bioeconomy in the region can be seen as a new way of addressing the challenges of achieving inclusive and sustainable development, as it could channel the problems of equity, distribution, poverty, and territorial imbalances. At the same time, while ensuring the competitiveness and sustainability of economic and industrial sectors, it could promote the urgent need to adapt to and mitigate climate change (IICA, 2019d).

Regarding the economic importance of the bioeconomy in the LAC countries, according to the Community of Latin American and Caribbean States, most Latin American and Caribbean countries, especially in South America, have revealed comparative advantages (VCR) in the export of bioeconomy products with low value-added, such as agricultural, food industrial and fishery products. On the other hand, only a few countries, such as Brazil, Costa Rica, Argentina, and Uruguay, reflect competitiveness in several bioeconomy products with medium value added such as paper, fiber, textiles, biodiesel, reliable energy, and more than one product with high value-added such as biochemicals, biopharmaceuticals, bioplastics, and biocosmetics. The rest of the region generally shows low competitiveness beyond essential products (IDB, 2018). Bioeconomy is a vehicle for new economic opportunities, innovative business models, resource efficiency, energy transition, and job creation in knowledge industries (Hohlwegler, 2022).One of the main challenges lies in the ability of countries to successfully achieve their different bioeconomy potentials in current reality, ranging from food security to recycling of biomass-based products, biomass feedstock production, and climate change mitigation.

The aim of the different statistical analyses that will be carried out on the secondary and primary data collected during this study is to visualize the importance of the bioeconomy sectors in the LAC region from different perspectives that focus on sustainable development.

1.3. Aims and Objectives

Recently, the bioeconomy as a concept and model of economic development has been studied and implemented as public policy in several world countries, mainly in the most developed ones. However, in regions such as LAC, available research is scarce and primarily based on examining global strategies for implementing the economic model in the region. Therefore, this thesis aims to provide a better understanding of the main sectors of the bioeconomy in Latin America and the Caribbean and how they relate to different aspects of sustainable development.

The research objectives are raised on three main aspects:

a) Analyze the most relevant bioeconomy sectors developed in the region in the last decade.
b) Determine the economic importance of these sectors, considering the information available in the official databases.
c) Understand the sustainable relationship of the bioeconomy sectors regarding essential aspects like food security, biomass production, innovative initiatives, and gender scientific production.

1.4. Research Questions

As mentioned in Figure 1, the research questions relate to the important elements of the research and seek to guide the author on the main aspects of the bioeconomy in the LAC region. Figure 2 describes the leading research question for this study.

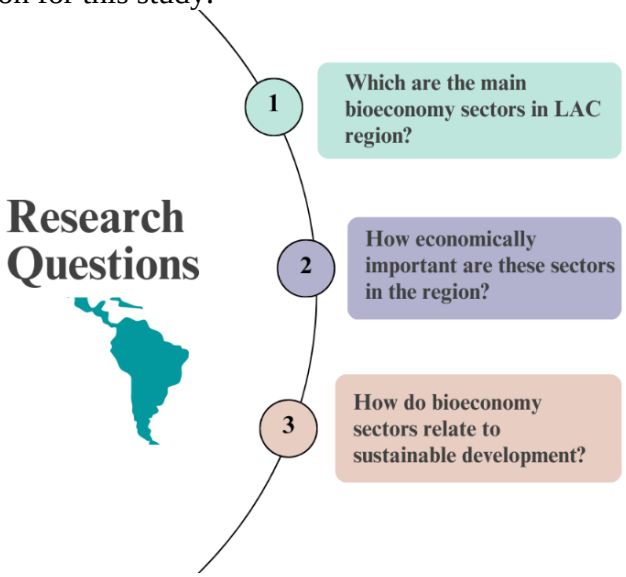

Figure 2. Research questions of the study
Source: Own construction

1.5. Research Hypotheses

According to (Anupama, 2018), the research hypothesis is a researcher's statement based on her/his prediction or expectation about the relationship between the variables being studied. It can be considered the core of the whole research procedure and considers three important fundamental aspects: the difference in the results, their relationship, and the interactions between the study variables.

Concerning the hypotheses to be considered in this research, the following have been considered:

- ✓ H1: Latin American and Caribbean region have four bioeconomy sectors, each of them with a level of development, economic contribution, and sustainability integration. They contribute with an important percentage to the VGA and trade balance of the countries studied.
- ✓ H2: Countries that have implemented bioeconomy policies are more competitive in bio-based value-added products, whereas others continue to rely on the primary sector.

- ✓ H3: Latin America and the Caribbean's bioeconomy sectors contribute to meeting chosen Sustainable Development Goals (SDGs) by fostering economic growth, resource efficiency, and environmental sustainability.
- ✓ H4: Biofuel production in Latin America and the Caribbean exhibits a dual impact on sustainable development.
- ✓ H5: Gender inequities remain in bioeconomy frameworks across Latin America and the Caribbean, with women having limited access to scientific research possibilities
- ✓ H6: Using sustainability assessment methodology allows for a thorough review of the environmental, economic, and social aspects of Latin America and Caribbean bioeconomy sectors.
- ✓ H7: Bamboo integration into the bioeconomy sector in Latin American countries, notably in construction, has the potential to improve sustainability across three dimensions. These effects may promote the development of a more sustainable bioeconomy in the region, with bamboo serving as a crucial material.

1.6. Significance of the study

This study provides a critical and timely contribution to understanding the structure, value, and transformative potential of bioeconomy sectors in Latin America and the Caribbean, a region characterized by vast biodiversity, deep socio-economic inequalities, and strategic importance for global sustainability. Despite the region's rich natural capital and emerging policy frameworks referencing the bioeconomy, this research reveals significant asymmetries in data availability, sectoral integration, and institutional recognition of value-added bioeconomic activities. By identifying and classifying key sectors across eleven countries, the study fills a critical knowledge gap and offers the first regionally comparative analysis of bioeconomy value added in LAC economies.

The research advances the discourse on sustainable development by bringing a Global South perspective into the essentially debate on bioeconomic transitions. It challenges dominant models by emphasizing locally embedded, socio-economically inclusive, and environmentally resilient bioeconomy pathways. Using mixed methods, including input-output analysis, bibliometrics, and life cycle assessment, the study also demonstrates methodological innovation in measuring and evaluating bioeconomic contributions where data limitations persist.

At the policy level, this work holds the potential to inform national and regional strategies by uncovering gaps between institutional ambitions and actual accounting practices. The findings underscore the need for harmonized, transparent indicators that capture the diversity of bio-based sectors and promote their integration into development planning in a way that recognizes both economic and non-economic contributions.

Finally, the study strengthens the argument for a more inclusive and equitable bioeconomic transition in LAC. The focus on sustainability and social impact, including the case study of bamboo in Ecuador, also highlights the potential for these sectors to contribute to climate resilience, local employment, and well-being.

2. LITERATURE OVERVIEW: CONCEPTUALIZING BIOECONOMY SECTORS IN LATIN AMERICA AND THE CARIBBEAN

2.1. Description of the Latin America and Caribbean Region

Latin America and the Caribbean (LAC) comprises 33 developing countries, with a vast coastline facing the Pacific Ocean on the western seaboard and the Atlantic Ocean/Caribbean Sea on the eastern coast (International Marine Organization, 2018).The LAC region contains 8 of the world's 17 most megadiverse countries, situated in the Andes-Amazon Basin (including Ecuador, Bolivia, Peru, Colombia, Brazil, and Venezuela) and Mesoamerica (including Nicaragua, Costa Rica, Honduras, Mexico, Panama, among others). Other ecosystems unique to the region are also rich in biodiversity, such as the desert of northern Chile-Southern Peru, the Argentine pampas, and Argentine-Chilean Patagonia, besides marine biodiversity in the Pacific, Caribbean, and Atlantic oceans.

Due to its immense biodiversity and natural resources, Latin America and the Caribbean region are considered the areas with the most significant natural capital in the world. Extraction of these resources has been the mainstay of the LAC economies (Boeri et al., 2020). In terms of water, soil quality, and land availability, the region has the most significant biomass production (Interamerican Institute for Agriculture Cooperation, 2019). These resources contribute more than the global average to the quality of life of human beings due to its high level of biodiversity (Rodríguez et al., 2017a; Sasson & Malpica, 2018). Various studies also show that the region's countries have rich mineral, fossil, and biological resources that have shaped their economies for centuries (Prado, 2013).

The region is home to 650 million people in different countries, with wealth and prosperity coexisting alongside vulnerability and extreme poverty, especially in rural areas (United Nations, 2022). One of the region’s main problems is income inequality among the population. However, it has been reduced recently, and Latin America and the Caribbean remain the world's most unequal regions. By 2021, according to OXFAM, the wealthiest 10% of the Latin American population had amassed 71% of the region's wealth (OXFAM International, 2021). According to the United Nations, the unequal countries in Latin America and the Caribbean are Brazil, Haiti, Guatemala, Bolivia, Paraguay, Panama, Colombia, and Honduras; the most prevalent problems in them are gender discrimination, land and income concentration issues, poverty more marked in rural areas and among ethnic minorities, exclusionary education systems, and regressive tax systems.

Figure 3 shows the high rates of inequality in income distribution in each of the region's countries and the territorial disparities that these data represent among the population that lives in extreme poverty, which is a sign of economic and social inequalities. On the same path, Figure 4 shows the GDP per capita in the world; as can be seen, the differences between continents are considerable. Regions such as the Caribbean, Africa, and Latin America report lower per capita incomes than other continents. Within the countries of the LAC region, territorial heterogeneity is also evident. All represent areas within the country at different stages of development and with high GDP per capita disparities; in some cases, there are metropolitan territories with higher GDP per capita than in Latin America, such as Brazil (regions of Sao Paulo and Rio de Janeiro), Argentina (the Autonomous City of Buenos Aires, Cordoba, and Santa Fe) and Chile (Metropolitan Region of Santiago)(Llungo Ortiz, 2018).

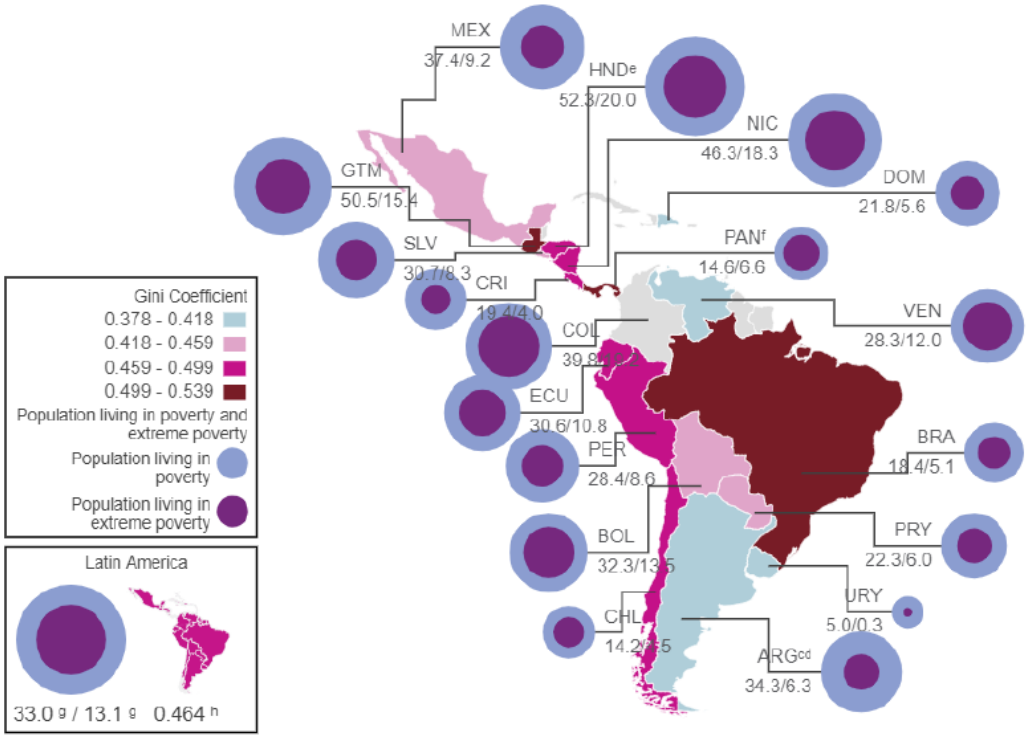

Figure 3. Poverty and income distribution in the LAC countries
Source: (ECLAC, 2022)

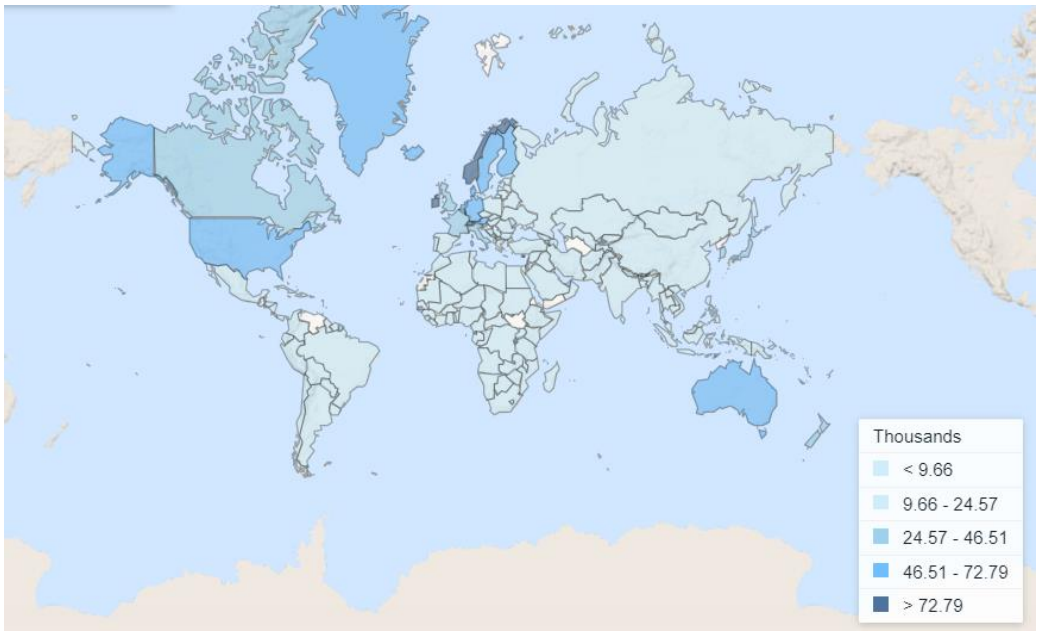

Figure 4. GDP per capita (current USD).
Source:(World Bank, 2021)

LAC remains exposed to a volatile global, regional, and national geopolitical and economic scenario, marked by crises related to recent events such as the 2019 COVID epidemic and the current war in Ukraine. Economic growth in LAC is estimated to reach 3.2% of GDP in 2022 and is projected to fall to only 1.4% in 2023 (ECLAC, 2022).

These latter scenarios have led to a slowdown in economic growth and sluggish job creation. These are compounded by other natural risks facing the region, such as the increased frequency of disasters and the impact of climate catastrophes.

As a result of the post-green revolution development models adopted by LAC countries, natural resources and import substitution have driven their economic growth. Figure 5 shows the GDP composition of the sectors in LAC countries. However, the primary sector does not have as much weight in the general composition; it is one of the most critical sectors in the countries' trade balance since raw materials are exported in many of them. Value-added products are imported, contributing to around 19.3% of the economically active inhabitants. The secondary sector is considered a mixture of extractive, manufacturing, and industrial activities, and it is fundamental, especially in oil-producing countries whose economies depend on exports of these non-renewable resources. Finally, the third sector, corresponding to services, has the highest share during all the periods evaluated.

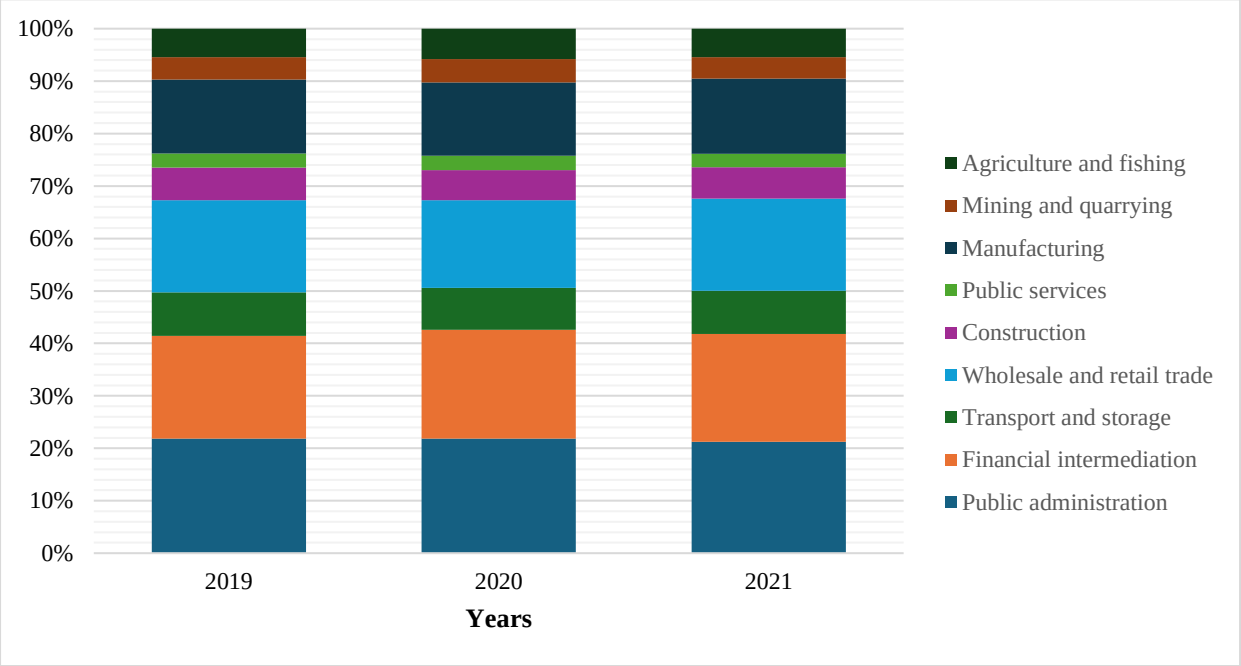

Figure 5. Evolution of the total value added of GDP by economic activities (percentage)
Source: Own construction base on CEPAL, 2021

According to Schmidtke et al. (2014), the analysis of several countries in the LAC region on the relationship between the volume of national GDP and the composition of exports of goods and services revealed that countries that overly depend on commodity exports are vulnerable to high price volatility and that those countries with a more significant primary sector generally have lower GDP compared to others in the region.

In the LAC region, the primary agriculture sector has an essential role in producing food and ecosystem services that benefit the region and the world (World Bank, 2020b). The figure above shows that it accounts for 5 and 18 percent of GDP in 20 LAC countries, even more when considering broader contributions through food systems.

The region has positioned itself as one of the most important exporters of agricultural products. LAC countries are major exporters of maize, soybeans, poultry, pork, coffee, animal feed, cacao beans,

sugar, fruits, flowers and vegetables (International Food Policy Research Institute, 2020). In 2017, Brazil was the biggest exporter of food and agricultural commodities in the region with ($79.3 billion), followed by Argentina ($35 billion), Mexico ($32.5 billion), Chile ($17 billion), Ecuador ($10.4 billion) and Peru ($8.8 billion).

Meanwhile, several LAC countries are also major importers of agricultural products, including Mexico, one of the leading importers of corn, pork, soy, dairy products, and poultry, and Brazil, one of the top importers of wheat (OECD & Food and Agriculture Organization of the United Nations, 2019). Due to several factors, Latin America and the Caribbean are considered one of the most vulnerable geographical regions to climate change. One of these is the exploitation of natural resources and the export of raw materials as the primary internal development model of the countries, making them highly dependent on extractive economic models. A second factor is that millions of people are highly vulnerable to the risks of natural disasters due to high levels of inequality and poverty within the countries (Cárdenas et al., 2021).

Land use is a critical environmental matter that challenges environmental security in Latin America and the Caribbean. Many countries expand their agricultural frontiers by clearing native forests and rainforests to create land for crops to meet growing food and energy needs (Pastrana Buelvas Miguel Burgos Giraldo, 2021).

Aside from this significant economic activity, mining and logging have been identified as key issues for developing Latin America. But these activities cause significant loss of biodiversity, impact local resources, and have become a source of social conflict in countries including Peru, Bolivia, Ecuador, Brazil, and Colombia (Cárdenas et al., 2021; Pastrana Buelvas Miguel Burgos Giraldo, 2021).

In summary, Latin America and the Caribbean countries have a great diversity of natural resources on which their economic development has been based. However, as mentioned in the data above, most countries have significant socioeconomic disparities that must be reduced to achieve sustainable economic growth. Promoting bio-economic sectors, which take a more holistic approach to environmental, economic, and social issues, is one of the financial strategies several developed countries have adopted to achieve this goal.

2.2. Importance on Bioeconomy at the Global and Regional Level

2.2.1. General Concepts

The bioeconomy term was used for the first time by the Biomass Research and Development Board in 2001 to describe a new model of economic development in a technological environment that conserves natural resources and ensures long-term sustainability (Pavone, 2012).

There are several current institutional definitions regarding the bioeconomy. According to Food and Agriculture Organization of the United Nations (2018b)bioeconomy is defined as *"the knowledge-based production and utilization of biological resources, processes, and principles to provide sustainable goods and services across all economic sectors*." This concept has three crucial elements:

1. Renewable biomass utilization and efficient bioprocesses to achieve sustainable production.
2. Enabling and converging use of technologies (including biotechnology).
3. Cross-sector integration of agricultural, sanitary, and industrial applications.

The global definition recently adjusted at the Global Bioeconomy Summit in 2018 refers to bioeconomy as the use, conservation, and production of biological resources from the land, air, and sea, including scientific and technological knowledge, for the sustainable provision of materials, energy, bio-based products, and services without compromising the resources of future generations (GBS, 2018).

In the study of Hodson De Jaramillo et al. (2019a)they conclude that the bioeconomy seeks to reduce energy generated from non-renewable fossil fuels and encourage using renewable resources. This is possible through environmental, social, and economic sustainability frameworks and strategies that encourage the production, processing, and consumption of biological materials and minimize polluting waste.

On the same path concerning the agriculture sector Rodríguez et al. (2017b)explains that the bioeconomy is based on the transition from fossil fuel dependency to a position in which agriculture contributes to food safety and biomass production as a renewable raw material for energy generation, industry, and other uses.

According to Linser & Lier (2020), bioeconomy is closely related to accomplishing the Sustainable Development Goals of the United Nations; approximately 14 out of 17 SDGS are considered relevant to this economic model. In addition, bioeconomy can help to address at least four global and crucial challenges: a) Global population growth, b) Global demand for biomass, exacerbating the scarcity of natural resources; c) The awareness that fossil fuels will disappear in the long term; and d) Climate change alarm (Food and Agriculture Organization of the United Nations, 2018b; Perišić et al., 2022).In summary, the SDG bioeconomy relationships can be grouped into ecological, industrial, and socio-economic.

On the one hand, for the industrialized countries, the main concerns revolve around issues related to the environment. On the other hand, developing countries' main concerns are the satisfaction of basic needs and the reduction of poverty and population pressure (Lewandowski, 2017).

2.2.2. Importance in the Global Level

In addition to the growing number of countries with bioeconomy strategies and policies, the emergence of the bioeconomy as a global concept is also reflected in scientific research. Figure 6 presents the number of scientific publications on bioeconomy in the last 15 years. From 2005 onwards, the article's production has rapidly increased and gained significant attention from academics and researchers.

According to the GBS (2018), the bioeconomy is a crucial model that has gained importance worldwide. It is certain in countries such as France, the Netherlands, Germany, Russia, Japan, and Finland. At the beginning of 2018, nearly 50 countries included defined bioeconomy policies in their development plans. These varied strategies emphasize the industrialization of biomass, bioenergy, biotechnological applications, bioindustry, the green economy, and the blue economy (economy of the oceans). Figure 7 represents the global map of countries with defined policies or strategies in the bioeconomy.

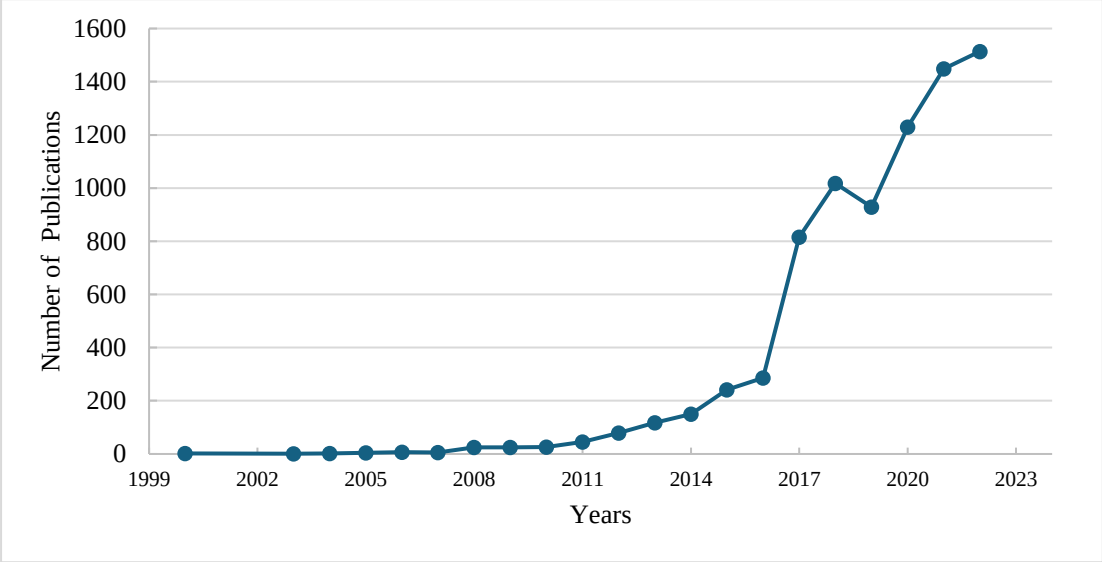

Figure 6. Number of publications listed in Web of Science that refer to the bioeconomy[1].
Source: Own construction based on Web of Science database

Figure 7. Bioeconomy policies around the world
Source: (GBS, 2018)

Based on European Commission datasets and publications, the bio-based economy includes sectors such as agriculture, fisheries and aquaculture, food and beverage, forestry, food products, biochemical, enzymes, wood-based industry, bioenergy, biopharmaceutical, and biofuels (Kuosmanen et al., 2020). However, the sector composition may vary from country to country due to differences in the bioeconomy concept used in each nation.

[1] Note: The graphic captures the number of entries that have one of the following expressions in abstracts, titles and keywords: "bio-based economy", "biobased economy", "bioeconomy" or "bioeconomy". Source: Compiled by the author based on Web of Science.

The research of Bracco, Calicioglu, Gomez San Juan, et al. (2018a), reflect that the different priorities and strategies in the country's economic systems, related to the sectors and sub-sectors considered in the bioeconomy, varied between the six nations analyzed. In the case of the Netherlands, their strategy focuses on the bio-based economy, except for the agri-food sector. Instead, in the United States, the bio-economy sector is limited to the industries of bio-based products, apart from the food, livestock, energy, feed, and pharmaceutical industries.

In the case of Argentina, the bioeconomy strategy includes primary sectors such as agriculture, forestry, and fishing and secondary ones such as food production, pulp and paper production, and parts of textile, chemical, energy, and biotechnological industries. Agriculture, forestry, fisheries, manufacturing, and trade of bio-based products are included in the German bioeconomy. Malaysia includes agriculture, fishing, forestry, human food, animal feeds, health and wellness products, renewable energy, and chemicals (Bracco, Calicioglu, Juan, et al., 2018). South Africa's bioeconomy strategy focuses on agriculture, industrial and environmental bio-innovation, and health. However, except for the European Union countries, there are still no developed metrics to monitor performance and indicators of bioeconomy in other regions (Food and Agriculture Organization of the United Nations, 2018a).

Globally, the importance of the bioeconomy can be seen in several ways:

a) Economic growth: The bioeconomy has the potential to generate economic growth in all sectors, both primary and secondary, and to create new jobs. It can contribute to rural development, export growth, and the reduction of fossil fuel dependency.

In the case of the United States, the bioeconomy has a direct economic impact of about $210 billion, with indirect benefits pushing the total impact to more than $830 billion. Across multiple industries, the sector supports 430,000 jobs (Biotechnology Innovation Organization, 2024) .

One region that monitored the economic value of bioeconomy sectors is the European Union. According to the Bioeconomy Monitoring System, the bioeconomy contributes around 614 billion euros, representing 4.7% of the EU-27 GDP. To remark on the economic importance of bioeconomy in the European Union, figure 8 shows the bioeconomy value added per sector. The most important sectors are agriculture and food industries, followed by wood products and forestry, and in a small proportion, bio-based industries (Ronzon et al., 2020).

The contribution of the primary bio-based industries is 13.3 million persons. From the same source and year, 17.5 million jobs were related to bioeconomy strategies in the EU, which is 8.9% of the EU-27 total employment. Romania has the highest bio-based share in this region, followed by Poland and Spain.

The study of Czyżewski et al (2021), shows the development of the bioeconomy in certain EU countries as a function of their overall level of economic development. The highly developed countries, such as Germany or Denmark, were characterized by a higher efficiency of the bioeconomy sector than the moderately developed countries, such as Hungary, Slovakia, and the Czech Republic. The development of the bioeconomy is related to various factors such as the level of GDP, the share of agriculture in gross value added, the share of employment in agriculture and hunting in total employment, the share of expenditure on R&D, the unemployment rate, the productivity of resources, the share of people with tertiary education or emissions of pollutants into the air. The more bioeconomically advanced countries have high resources in agriculture and aquaculture, and partly in

forestry, where the contribution of primary resource production is smaller in the less bioeconomy-developed countries (Brunori, 2013; M'barek & Wesseler, 2023).

A cross-country comparison of 22 EU countries done by Dolge et al., (2023) ,grouped various indicators of the main dimensions of a sustainable bioeconomy, and determined the Complex Bioeconomy Sustainability Index for eight years, which confirms what has been mentioned above. The results of the index show that Denmark, Sweden, Germany, the Netherlands, and Belgium are the leaders in the sustainability of the bioeconomy. On the other hand, Latvia, Estonia, and Hungary have the lowest scores. The results show that socio-economic financing and government support play the most critical role in improving the overall sustainability of the bioeconomy for countries. In this sense, government funding is crucial for all the bioeconomy sectors to provide the environment for increasing productivity and reducing externalities (Zilberman & Wesseler, 2023).

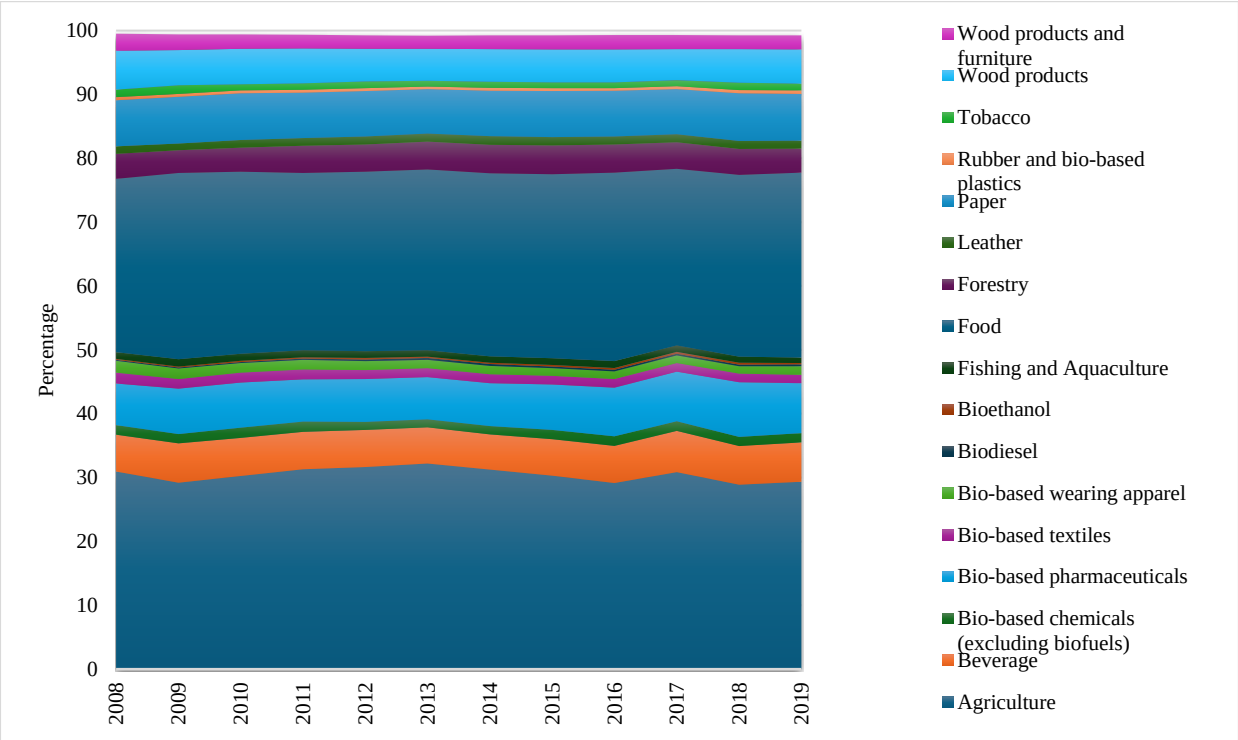

Figure 8. Historical Evolution of the Bioeconomy Value Added per Sector in the EU
Source: Own construction based on (European Commission, 2023b)

b) Environmental sustainability: It encourages sustainable practices that can help reduce greenhouse gas emissions and mitigate climate change. Using biological resources more efficiently can also help reduce waste and pollution. Concerning environmental indicators, the contribution of the bioeconomy through Innovations and practices can reduce GHG emissions and promote the sequestration and storage of carbon in biomass and soils (European Network for Rural Development, 2018).

Climate change is an essential tool for the bioeconomy as it stimulates regulations, financing, and investments directly related to production (Indzere et al., 2021).Because of their strong links, various production processes generate CO2 emissions, consume energy, and produce waste. According to Climate Watch, the global carbon emissions from land use change were 49.76 CO2e GT(Watch,

2019). The top emitters are China, the United States, India, Russia, and Japan. Among the sectors, energy makes up nearly three-quarters of global emissions, followed by agriculture, manufacturing, and industrialization.

c)Food security: The bioeconomy can contribute to food security by increasing the availability of nutritious food and reducing waste. It can also contribute to diversifying food production systems and reducing dependence on a limited number of crops. Through sustainable intensification of crop and livestock systems that increase yields, the bioeconomy can transform food systems and strengthen local value chains. This, in turn, would enable the reuse and recycling of food resources to achieve the necessary sustainability approach (E. Trigo et al., 2023b; Von Braun et al., 2020).Another strategy proposed by the bioeconomy is to diversify primary agricultural production systems, increase the use of biological inputs, and diversify rural incomes by generating bioenergy, bioindustries, and environmental services, which can strengthen the resilience of food systems.

Food systems consider all the activities involved in the production, processing, transformation, packaging, transport, and consumption of food (United Nations, 2021b), which can be seen as an integral part of the bioeconomy concept as an approach to development. To achieve transformation towards more sustainable and equitable food systems, the UN Food Systems Summit has identified five pathways' actions about the bioeconomy (figure 9).

Figure 9. Action Tracks determine by the Food System Submit 2021 about Bioeconomy
Source: Own construction based on (United Nations, 2021b)

d) Health and welfare: Biotechnological methods can contribute to developing new medicines, vaccines, and other health products. For example, innovative agri-food research transforms food systems by increasing food supply and making diets healthier, more nutritious, and less hazardous. As a result, safe and nutritious food will provide lifelong health benefits and reduce health system costs (E. Trigo et al., 2023b).

The following initiatives in the bioeconomy are examples of improving nutrition and health in the food system.

- ✓ Food innovations contribute to dietary diversification, especially with new protein sources such as microalgae and insects (Ordoñez-Araque & Egas-Montenegro, 2021; Ullmann & Grimm, 2021).
- ✓ Emerging technologies such as cultured meat products as a sustainable source of protein (Post et al., 2020).
- ✓ Innovations in plant breeding technologies, such as those used in the production of genetically modified (GM) crops (Klümper & Qaim, 2014; Smyth, 2022).
- ✓ Nutritionally enhanced foods improve individual nutrient intakes and prevent and treat significant killers such as cancer, diabetes, cardiovascular disease, and hypertension (Wesseler et al., 2017).

2.2.3. Importance in Latin America and the Caribbean

According to Boeri et al. (2020), due to its immense biodiversity and natural resources, the Latin American and Caribbean region is considered the region with the most outstanding natural capital in the world. The region has the most significant biomass production in terms of water, soil quality, and land availability. Because of its biodiversity and climatic conditions, its contribution to people's quality of life is higher than the world average. In addition, the LAC region holds prosperous fossil and mineral resources, which have shaped its economy for centuries.

As a result of the Green Revolution, the economic development models adopted by Latin American countries were based on exploiting their natural resources and substituting imports. That is why the importance of the bioeconomy concept since it emerged as a socioeconomic model that reduces fossil resource dependence, endorses green energetic transition, and promotes the production and intensive use of knowledge of biological resources. Bioeconomy can allow the sustainable supply of goods and services in all economic sectors (food, bioenergy, fiber, agriculture and bio-inputs, health products, industrial components, and bioplastics) while conclusively contributing to human welfare and decarbonizing the economies to comply with global environmental agreements for sustainability (FAO, 2019).

Bioeconomy in the Caribbean and Latin American countries in a global context has two main challenges. In international terms, the LAC region has a fundamental role in food, energy, and fiber production balances, contributing to the environmental sustainability of production ecosystems. The bioeconomy, based on improvements in agriculture and biomass production, is a new model of equitable growth and opportunity within the region's borders (Chavarría et al., 2021; E. J. Trigo et al., 2013). In light of the comparative advantages of the Caribbean and Latin American countries, Trigo et al. recognized six milestones where bioeconomy initiatives provide a holistic regional approach. Those milestones are: *"(a) eco intensification of agriculture; (b) biodiversity resources exploitation; (c) bio-refineries and bio-products; (d) biotechnology applications; (e) ecosystem services; and (f) value chain efficiency improvement"* (E. Trigo et al., 2023b).

According to the Community of Latin American and the Caribbean States, most Latin and Caribbean countries, especially South America, have revealed comparative advantages (VCR) in exporting

bioeconomy products with low added value, such as agricultural, agro-industrial, and fishing products. On the other hand, only a few countries, such as Argentina, Brazil, Costa Rica, and Uruguay, reflect competitiveness in various products of the bioeconomy with medium added value such as paper, fiber, textile industry, biodiesel, reliable energy, and more than one product with high added value such as bio-based chemicals, biopharmaceutical industry, bioplastics, and biocosmetics. The rest of the region generally shows low competitiveness beyond essential products (IDB, 2018).

In the study carried out by (Rodríguez et al., 2017a)they first approximated the economic importance of the bioeconomy by analysing the composition of exports in twenty-two Latin America and the Caribbean (LAC) countries, considering exports as a relevant indicator of the economic importance of a sector or productive activity. Figure 10 presents the composition of the countries' exports in the region, which were analyzed based on five main criteria.

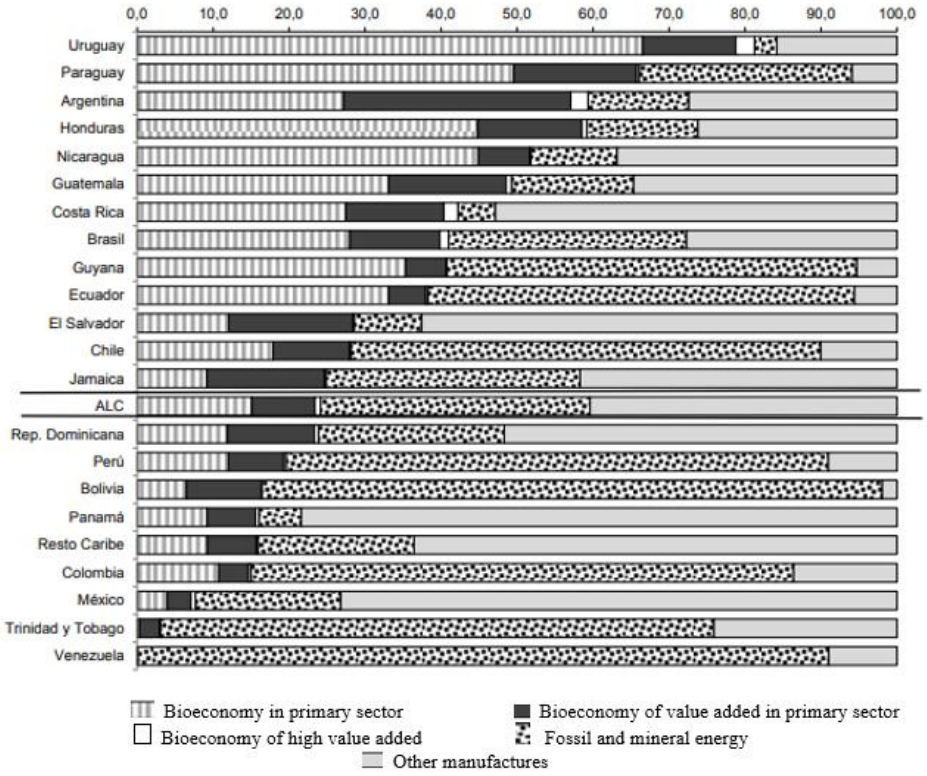

Figure 10. Importance of the bioeconomy in the export composition of 22 countries in the Latin America and Caribbean region
Source: (Rodríguez et al., 2017a)

The study found a high share of bioeconomy exports (above the regional average of 24.2%) in countries such as Uruguay, Argentina, and Brazil. This group would be the countries in which the bioeconomy would have the most significant potential, as they have an essential bioeconomy export base and a relevant manufacturing export base, which facilitates the possibilities for the expansion of bio-based manufacturing production. Among the three types of products (bioeconomy, manufacturing industry, and mineral and fossil products), Brazil is the country with the best balance.

Regarding the contribution of bioeconomy to the GDP of Latin American and Caribbean countries, the information is limited; only a few studies provide data about this topic. According to IICA, (2021)in 2018, Uruguay's bioeconomy generated USD 8.448.277 million of added value, representing 46.2% of the production of goods and merchandise and a 14.2% contribution to the country's GDP.

In 2016, US$326.1 billion of sales worldwide were estimated to be attributable to the Brazilian bioeconomy. In the same year, sales attributable to the bioeconomy reached US$285.9 billion inside Brazil, representing 13.8% of the local GDP.

For Colombia, the contribution of the bioeconomy to the GDP was around 6,35%; from this percentage in 2017, 52% for the primary sector, the manufacturing sector 28%, and the services sector approximately 20% (Alviar et al., 2021). Employment related to the bioeconomy in Colombia was four million jobs in 2017, representing 18.2% of the total labor force. In terms of greenhouse gas emissions in 2019, Colombia attained a level of 216.67 million tons of CO2eq, which mainly belonged to the primary sector, with a share of 46%, followed by the manufacturing and transport sector with 13% and, finally, with 12% the industry and construction sector (Climate Watch, 2019).

In the case of Argentina, according to the study of (Buryaile et al., 2012a) in 2012, the bioeconomy represented 15.4% of the GDP. It represents around USD 72 675 million, of which the primary sector accounts for 58% of the total value added of the bioeconomy (8.9% of GDP). The remaining 42% pertains to the manufacturing industry (6.5% of GDP). Moreover, 72% of the industrial value-added is generated in agricultural origin (MOA) production, while the manufacturing output of industrial source (MOI) accounts for 28% of the biomanufacturing industry.

Regarding Mexico, although there is no specific data regarding the contribution of the bioeconomy to the country's GDP, according to the Mexican Secretariat of Economy, the biotechnology industry (as a strategy of bioeconomy) was estimated to contribute 2016 307,000 million dollars. Such approximation also includes the health and pharmaceutical industries, where Mexico is the leading country (Izquierdo Tolosa & Pérez Zazueta, 2014).However, according to a study by the OECD (2009), in 2030, the contribution of biotechnology to this country's gross value and employment will be 0.73% in the pharmaceutical area, 3.79% in primary production, and 6.23% in the industry sector.

Regarding some Caribbean and small Central American countries, some academic studies refer to the contribution to the bioeconomy in these countries. In the case of Cuba, the bioeconomy contribution from an economic perspective based on the time series and reports from the National Bureau of Statistics and Information of Cuba showed an average of 4%; the most significant givers are sectors based on biological resources like agriculture, livestock, and forestry (Rangel Cura et al., 2015).

For Nicaragua, (Rangel Cura et al., 2015) measured the contribution of the Nicaraguan bioeconomy using the Canadian approach to the bio-based economy, following the data and records available in the Central Bank of Nicaragua. The results showed that bioeconomy contributed to the country's GDP by 28% during the period 1994-2000, while in the reference year of the study (2006), a constant 7% was estimated; the main contributor sectors are the organic chemical industry, followed by the agriculture and crops activities, and the health component with medical and pharmaceutical industries.

Although no specific studies are measuring the contribution of the bioeconomy to the rest of Latin America, in most of the countries of this region, the bioeconomy is considered an alternative model for sustainable development and green growth, especially given the mega biodiversity that the region offers as a countless potential for biomass production and usage.

Regarding the different bioeconomy strategies that contribute to the economic growth in Latin American and Caribbean countries, the following statements summarize the region. For Brazil, Argentina, and Uruguay the successful application of bioeconomy engrossed mainly in bioenergy production; Colombia sees the use and quantification of biodiversity resources as a starting point to

enter into bioeconomy; for Chile the bioproducts obtention and production; Costa Rica, with initiatives of value addition in agri-food chains; and finally Mexico, where the start-ups and spin-offs already have bio-based products in the market such as biofertilizers, bio fungicides, ethanol production from less conventional sources (cyanobacteria), bioplastics and industrial enzymes and others developments.

Finally, the Bioeconomy Council (2018) regarding the policy strategies for the bioeconomy in LAC countries, it points out that the bioeconomy has gained importance in Latin America and the Caribbean, even if there are no specific national policy strategies for the bioeconomy yet. However, countries such as Brazil, Colombia, Argentina, and Ecuador have already announced their disposition to prepare appropriate policy documents. Moreover, Brazil and Argentina are among the leaders in bioenergy production and are among the top five users of genetically modified crops. Colombia, Paraguay, and Uruguay have taken the first steps in the knowledge-based bioeconomy (bioprospecting, agricultural technologies). To sum up, these activities will help align the intentions of Latin America and the Caribbean with current initiatives and continue to develop bio-economy programs and policies.

2.3. Bioeconomy Sectors in the LAC region

By maximizing value addition and minimizing waste, the bioeconomy can promote the sustainable use of natural capital to produce food, industrial goods, and energy in Latin America and the Caribbean countries (Bucaram-Villacís, 2020).There are widely developed bioeconomy sectors in some countries in the region related to the production of biofuels within the framework of the agricultural area. However, other bioeconomy sectors in the region related to fisheries, aquaculture, and forestry, among others, have not yet implemented modern business models that are sustainable in the long term.

Table 1 presents the Revealed Comparative Advantage (VCR)[2] Of the LAC region countries for the items included in the three bioeconomy categories. Based on the research of tRodriguez, 2017) the countries with VCRs in the most items are Brazil (9 out of 12), Uruguay (8 out of 12), Argentina, and Costa Rica (7 out of 12). Only Mexico, Trinidad and Tobago, and Venezuela have no VCRs in any export item of the bioeconomy.

Among the countries with VCRs in the textile and leather manufacturing sector are all those in southern South America (Argentina, Brazil, Paraguay, and Uruguay); all these countries produce fibers and have significant livestock production. El Salvador and the Dominican Republic also have VCRs, but this is more likely to be associated with the textile maquila of natural fibers.

Only Argentina, Brazil, Costa Rica, and Uruguay have VCR in more than one high-value-added sector; Argentina and Uruguay in bio-based chemicals and biocosmetics; Brazil in bioplastics and biocosmetics; and Costa Rica in biopharmaceuticals and biocosmetics.

[2] Comparative Advantage (VCR) is a "crude" measure "of a country's competitiveness in the international market in an area of interest. For a given item and for a given country, it is measured as the ratio of that item's exports as a percentage of the country's total and the share of world exports of that item in the total world trade. If the value is greater than one (1) the country has revealed comparative advantages, s the share of its trade in the item is higher than the item's share in world trade.

Table 1. Absolute values of revealed comparative advantage in exports of bioeconomy products, 2010-2015 for Caribbean and Latin American (14 countries)

Country	Bioeconomy of Primary Sectors			Bioeconomy of value added in the primary sector						Bioeconomy of high value-added			
	Agriculture and Agro-Industry	Fisheries, aquaculture, and sub-products	Forestry and wood industries	Food Industry	Paper industry pulp	Fibers, Textiles, and Leather	Biodiesel	Bioethanol	Solid Energy	Bio-based chemicals	Biopharma Industry	Bioplastics	Biocosmetic Industry
Argentina	6.00	2.79	0.36	9.48	0.54	1.49	29.50	0.34	1.06	1.38	0.33	0.75	4.81
Bolivia	1.42	0.00	0.98	3.07	3.02	0.48		12.09	0.16	0.03	0.00	0.01	0.53
Brazil	6.58	0.15	1.28	2.18	2.53	1.46	0.16	13.43	1.23	0.70	0.07	1.25	2.55
Chile	2.37	7.92	3.73	1.77	3.55	0.16		0.03	10.11	0.21	0.01	0.79	0.07
Colombia	2.50	0.52	0.12	0.84	0.67	0.55		0.01	0.13	0.20	0.04	1.10	0.09
Costa Rica	6.19	1.88	0.99	3.85	1.10	0.26		5.80	0.00	0.71	1.25	0.40	1.07
Ecuador	4.49	18.96	1.67	1.48	0.21	0.24	0.89	2.51	0.58	0.16	0.03	0.03	0.20
El Salvador	2.48	2.42	0.21	3.11	4.02	1.61		10.89	0.20	0.10	0.02	0.12	0.09
Guatemala	7.70	1.17	0.96	3.87	1.76	0.85		25.99	0.08	0.47	0.06	0.33	1.26
Guyana	6.27	8.20	5.66	1.77	0.22	0.01		0.04	0.55	0.02	0.00	0.04	0.02
Honduras	9.26	2.11	0.27	0.32	0.28	0.01			0.85	0.06	0.02	3.40	0.38
Jamaica	2.02	1.12	0.16	4.14	0.10	0.02		78.35	0.02	0.02	0.01	0.01	2.66
Mexico	0.38	0.35	0.14	0.84	0.33	0.26		0.03	0.16	0.36	0.06	0.77	0.64
Nicaragua	9.43	8.17	0.54	1.92	0.18	0.76		2.43	0.12	0.04	0.08	0.03	0.82
Panama	1.29	4.47	1.06	1.27	0.61	1.57		1.15	0.01	0.21	0.34	0.02	0.19
Paraguay	11.91	0.00	0.96	4.68	0.17	1.74		1.45	9.59	0.07	0.09	0.01	4.21
Peru	2.04	4.55	0.59	2.13	0.22	0.63		3.30	0.00	0.22	0.01	0.05	0.63
Rep.Dom	2.86	0.23	0.15	2.01	1.08	3.46		1.10	0.22	0.19	0.11	0.13	5.17
Tri. Tog	0.05	0.12	0.06	0.75	0.38	0.01		0.51	0.00	0.00	0.00	0.02	0.00
Resto Caribe	1.94	4.51	1.39	1.94	0.45	0.73		11.32	0.07	0.11	0.16	0.03	1.18
Uruguay	14.29	2.92	8.69	1.14	0.91	5.37	0.01	0.04	26.45	1.14	0.54	0.28	2.39
Venezuela	0.00	0.02	0.01	0.01	0.00	0.01		0.05	0.06	0.16	0.02	0.01	0.51

Source: Own construction based on (Rodriguez, 2017)

To ratify the previous statement, Ordoñez Olivo & Lakner (2023b) in their research, they point out that bioeconomic sectors developed in Latin America are concentrated mainly in producing biofuels, with Brazil and Argentina considered the region's major producers.

According to Skoczinski et al. (2023) in 2022, the LAC region produced 13% of the global production capacity of biobased polymers, one of the fewer contributors than the rest of the world. Over the next five years, the forecast predicts a significant decline in the share of LAC and other world regions. Meanwhile, Asia's capacity is expected to increase to almost 63 percent by 2027.

Finally, regarding the value-added sectors of the bioeconomy, one of the main constraints in emerging economies such as LAC is the absence of policies and strategies to integrate key sectors related to the development of the bioeconomy, such as agribusiness, life sciences, and pharmaceuticals. Argentina, for example, has made consistent efforts to strengthen its role as a bioeconomy actor, with the capacity to produce biofuels for the world market and to be the third largest producer of GMOs. The country has approximately 200 biotechnology companies that make and process seeds, pharmaceuticals, biological products, and industrial inputs). It is also developing first-generation biorefineries based on

sugarcane, maize (ethanol), and soya (biodiesel) and taking its first steps in the direction of green chemistry (Moreno, 2016).

2.4. Major Challenges of Bioeconomy in Latin America and the Caribbean Countries

The bioeconomy offers Latin American and Caribbean regions a substantial chance to achieve sustainable development, reduce inequalities, and promote inclusive green economic growth. However, several challenges must be addressed to realize the bioeconomy's potential fully.
One of the first challenges to discuss is the lack of institutional frameworks since many Latin American and Caribbean countries do not have the legal and regulatory frameworks to support the development of the bioeconomy. This framework includes inadequate policies, weak intellectual property protection, and a lack of incentives for private investment. According to Bucaram et al. (2020), several institutional barriers delay the region's ability to capture the bioeconomy's known potential socioeconomic and environmental benefits. Some of these barriers are related to inadequate regulatory and policy frameworks and the lack of harmonization in classifying new bioeconomy products.

A second major challenge is the limited access to financing for bioeconomy projects in the LAC region, particularly for small and medium-sized enterprises that need extra support to escalate their business. The report of Global Bioeconomy Submit (2018), remarks that public funds available in LAC countries are scarce and usually restricted to initial research and development; the venture capital market hardly exists in most countries, and there is no culture of private sector innovation investment. The lack of available capital and the perception of high risk for bio-based companies are critical barriers to the sector's growth. The complex and costly process of applying for certification schemes for bio-based companies in the bioeconomy is also a barrier. Related to the financial aspect, the bioeconomy entails substantial investment in infrastructure, including research and development facilities, processing plants, and logistics networks. In many Latin American and Caribbean countries, there is limited infrastructure to support the development of the bioeconomy, making it difficult for companies to access markets and scale up their operations.

A third challenge pointed out by many authors is the limited research and development capabilities to support the development of new technologies and products that can be commercialized in the bioeconomy. These limitations include inadequate skills for developing bio-based new products, processes, and value chains. Another critical point is the limited entrepreneurial ecosystem with knowledge and experience in the business models for bioeconomy and socio-cultural barriers and behavioural biases for the consumption of bioeconomy products. A strong effort in human resource development and improved mechanisms for social participation are needed for a positive conversion to the bio-economy model in the LAC region (Global Bioeconomy Submit 2018, 2018). Bio-based products and processes require a new technological base, reflecting a reorganization of the R&D scientific skills and partnerships between academia and industry (European Commission, 2013). New and innovative bio-based strategies, which are more knowledge-intensive than conventional approaches, are also needed at the production and management levels of bio-based value chain products.

Finally, environmental and sustainable aspects are one of the main concerns related to bioeconomy models. Some facts are associated with the potential negative impacts on biodiversity, soil quality, and water resources. One of the challenges faced by the Latin American and Caribbean countries is to ensure the development of regulations and certification systems that aim to reduce the risk to food

security and the environmental impact of biofuel production (Falck-Zepeda Jose et al., 2010; Scarlat et al., 2015).

The study of Ordoñez Olivo & Lakner (2023), highlighted the concerns in the Caribbean and Latin America region regarding food security and the sustainable development of bioenergy sources such as biofuels, given that there is a strong link between them and land use, particularly for crops used to produce energy. In addition, eis & Gillen Brenes (2022), notes that there is a global debate about the tension between bioeconomy policies and strategies to ensure food availability and simultaneously use biomass for energy. Ensuring that the bioeconomy is developed sustainably and promotes environmental conservation is a crucial challenge for the region. Addressing these challenges requires a concerted effort from governments, the private sector, and civil society to build the necessary institutional, financial, and technological foundations for the bioeconomy to thrive in the LAC region.

3. MATERIALS AND METHODOLOGY

This chapter theoretically characterizes the research's methodological design and explains the different components of the study. Each subchapter explains the reasons for the type of methodological strategy used and the various data collection techniques employed to obtain primary and secondary data.

3.1. Research design

The design framework includes methods and procedures to collect, analyze, interpret, and discuss data. As a concept, the research design is described as the overall strategy to integrate the different components of the study coherently and logically, thereby ensuring you will effectively address the research problem (Thakur, 2021). According to Wright et al. (2016), the methods included in the design of a research study depend on the researcher's perspective on their theories, such as knowledge and reality, which are often shaped by the disciplines to which the researcher belongs. Many research designs are appropriate for diverse types of research studies. For the present study, a "descriptive design" will describe the main bioeconomy sectors in Latin America and the Caribbean countries.

According to Thakur (2021),descriptive analysis helps the researcher present the problem statement to help others better understand the need for this kind of research. Studies that look for population characteristics or units, such as countries, can be called descriptive ones. Under this perspective, the researcher identifies problems within the unit, looking for standard features or practices. (Siedlecki, 2020).As mentioned above, the study will describe the bioeconomy and its sectors in one of the most biodiverse continents. This description will be based on general data of the region and on the specifics in several countries where the bioeconomy sectors are estimated to have economic relevance. In summary, Figure 11 shows the graphical interpretation of the research design, which includes the entire framework of the study.

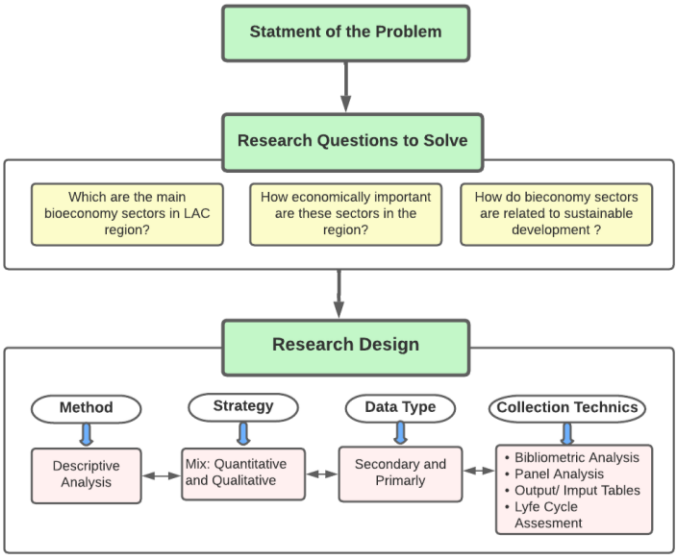

Figure 11. Research Design Chart
Source: Authors own construction

3.2. Research Approach

As a concept, the research approach refers to the overall plans and procedures adopted to conduct the investigation. It involves the general framework or methodology that guides the research design, data collection, and analysis (Kankam, 2020; SAGEPUB, 2016). There are three main research approaches and these approaches are qualitative, quantitative, and mixed (Hughes & Sharrock, 2016).

In the case of the present study, to answer the research questions established, the author decided to apply mixed approaches to generate the desired results and conclusions. According to Bazeley, (2002), combining qualitative and quantitative approaches can be defined as mixing research methods. These methods associate qualitative and quantitative research techniques, concepts, and data analysis in a single study.

Quantitative approaches have become famous based on the type of data, the method of analysis, the category of investigation, the approach to explanation, and the logic employed.

The proposed analysis model seeks to code bioeconomy sectors in Caribbean and Latin American countries qualitatively; the descriptive data obtained from these sectors can be converted into quantitative variables that explain the bioeconomy's relevance in the region and its relationship with the holistic dimensions of sustainable development.

3.3. Research Strategy

Mixed methods strategies combine quantitative and qualitative approaches, integrating and connecting both data types. The concept of mixing different methods originated in the '50s, with Campbell & Fiske (1959) who wanted to study the validity of psychological traits. The qualitative and quantitative data can be merged into one extensive database, or the results can be used side by side to reinforce each other's approaches. For example, qualitative quotes support statistical results (Creswell & Clark, 2017).

Among the three general mixed method strategies, the author will apply concurrent mixed methods for the present research. Convergence methods merge quantitative and qualitative data to analyze the research problem posed by the researcher, who collects the data simultaneously and integrates them to generate overall results (Molina-Azorin, 2016). Similarly, the authors can incorporate qualitative data into the process and quantitative data into the results (Yu, 2009). Table 2 describes the convergent analysis used for the present research, related to the main research questions, and the quantitative and qualitative procedures considered to merge the results to proceed with the discussion and conclusion of the study.

3.4. Data collection

Data collection is crucial in statistical analysis (Hox & Boeije, 2005). According to (FAO, 2015) the variables to be measured, the source, and the resources available determine the data collection methods.

Table 2. Convergent analysis used for the present research

RQ1: Which are the main bioeconomy sectors in Latin America and the Caribbean Region?			
Qualitative Procedures	Documentary and content analysis	Products	Description of the potential Bioeconomy Sectors in the LAC region
Quantitative Procedures	Bibliometric Analysis	Products	Cluster of the relevant bioeconomy sectors in the LAC region.
RQ2: How economically important are these sectors in the region?			
Qualitative Procedures	Semi-structured interviews with stakeholders involved in the bioeconomy of the region.	Products	• Written response data
Quantitative Procedures	Imput and output analysis of the supply and demand database tables (gross value added).	Products	• Indicators to evaluate the economic importance of bioeconomy sectors. • Sectorial Statistics of each sector
RQ3: How do bioeconomy sectors are related to sustainable development?			
Qualitative Procedures	• Documentary analysis • Case Study	Products	• Principals and Criteria • Descriptive interpretation
Quantitative Procedures	• Numerical links with bioeconomy and SDGs in the LAC region. • SDG 1,2: Panel data analysis between food security and bioeconomy sectors. • SDG 5: Correlation analysis of the bioeconomy gender policies instruments and the scientific production in the LAC region • SDG 9,11,13: Life Sustainable Cycle Assessment of the use of bamboo as a potential bioeconomy sector in Ecuador.	Products	• Results of the bibliometric analysis done in the first part. • Statistical significance of the impact on food security by bioeconomy sectors. • Comparisons of gender inclusion in bioeconomy instruments and gender gaps on the scientific production in the LAC countries. • Sustainable Impact Assessment of Bamboo in Ecuador.

Source: Author's construction

3.4.1. Data Type

According to Walliman (2010), data can be presented in two basic ways depending on the occurrence of an event. Primary data is considered when the observations were experienced and recorded, while secondary data are those obtained from written sources that interpret the primary record data.The fundamental difference between primary and secondary data is the procedure of collection; primary data refers to the data originated by the researcher for the first time, while secondary data is the already existing data collected by the investigator agencies and institutions previously (Ajayi, 2017).

In this research, the data study will be primarily based on secondary data from reliable governmental, institutional, international, and academic databases, which will allow an analysis of the main aspects of the bioeconomy sectors in the LAC region. Secondly, primary data will be collected through semi-structured interviews and surveys that complement the information analysis.

3.4.2. Collection technics

Determining the data collection methods and tools is a particular part of the research strategy since it helps explain how the information is collected and used and provides explanations of the data type

(Paradis et al., 2016). To solve the central hypothesis of this research, the collection techniques of quantitative and qualitative data that the author will use are the following:

- **Secondary analysis:** In this type of collection, the data content of secondary sources offers inputs for official statistics, historical archives, or online repositories to analyze and extract information relevant to answering the research objectives. The data analyzed may contain quantitative or qualitative information (European Commission, 2014).
- **Content Analyze:** This is a classical procedure for analyzing textual material. It is an empirical method for a systematic, intersubjective, transparent description of substantial and formal human communication (Flick, 2015).
- **Surveys and Interviews:** are a method of gathering quantitative and qualitative information from individuals (Walliman, 2010). These techniques will allow for interviews and paper-based questionnaires to understand the relevance of bioeconomy sectors in the LAC region.
- **Case study:** As was defined by Yin (2014), a case study investigates a contemporary phenomenon, "the case," in its actual context, especially the boundaries between these factors; it captures the circumstances and conditions of the situation and will provide social, economic, and environmental outcomes related to the unit of analysis.
- **Internet-based research:** a collection of data through online surveys, online experiments, social media analysis, or analysis of online communities and forums.

3.5. Data Analysis

Data analysis refers to the various analytical techniques to derive meaningful insights and draw the proper conclusion in a research study. To obtain the result that answers the research question of the present research, the following data analysis techniques will be used:

3.5.1. Bibliometric analysis

Bibliometric data analysis is a statistical method for collecting and analyzing big corps of scientific data (Donthu , et al., 2021). According to Chai & Xiao (2012), bibliometric analysis is a technique for quantitative literature analysis. It is one of the few quantitative approaches that can handle extensive scientific data and produce a high research impact. Glänzel (2003),argued that this methodology comprises components from mathematics, social sciences, natural sciences, engineering, and even life sciences.Bibliometric analysis can be used to discover emerging trends in article and journal performance, determine patterns of collaboration and research components, and explore the intellectual structure of a specific field in the existing literature (Donthu et al., 2021). For this research topic, the bibliometric data will be collected from the scientific database "Web of Science" using keywords related to the research topic.

For this research topic, the used keywords were:

TS=((("bioeconom") OR ("circular econom*") OR ("green econom*") OR ("sector*"))AND(("agricultu*") OR("forest*") OR("Aquacul*") OR("fishing*") OR("food and beverages*") OR("wood*") OR("paper*") OR("leather*") OR("biogas*") OR("biofuel*")OR("biodiesel")OR("ethanol*")OR("biomass*") OR ("biocosmetic*") OR ("bio-based*") OR ("biopharma*") OR ("biofiber*") OR ("biochemical*") OR ("bioplastics*") OR ("bio-*

services"))AND(("South America*") OR ("Latin America*") OR (“Brazil*”) OR (“Brasil*”) OR (“Argentin*”) OR (“Chile*”) OR (“uruguay*”) OR (“mexic*”) OR (“Cuba*”) OR (“Colombia*”) OR (“costa Rica*”) OR ("Ecuador*") OR ("Paraguay*") OR ("Peru*")OR("Venezuela*") OR ("Mexico*") OR ("Nicaragua*"))).*

The filters applied to better structure the data set included documents classified as scientific articles, book chapters, literature reviews, and conference proceedings. Only the English, Spanish, and Portuguese language versions were included in these documents. In addition, exclusion filters were applied to the years of publication. Those published in years before 2000 were not analyzed in the database. To analyze and visualize the corpus data, the researcher used the open-source software R package and R studio, which is a statistical package that provides a wide variety of statistical functions such as (linear and nonlinear modeling, classical statistical tests, time-series analysis, classification, clustering) and graphical techniques.

3.5.2. Panel Data Analysis

A panel analysis is a method of evaluation in which the same set of units is observed repeatedly over time in a cross-sectional manner (Wooldridge, 2009). According to A. X. Li (2019), panel data allow researchers to control entity-specific factors that can be unobservable and difficult to measure in a particularly useful causal inference.

In panel data analysis, to improve the quality and quantity of the data, it is necessary to combine time series with cross-sections to complement the study to be carried out (Yaffee, 2003).

In the context of this research, panel data analysis allows us to compare the impact of bioeconomy sectors on food security over time in several LAC countries.

3.5.3. Input/Output Analysis

In quantitative economic research, input-output analysis is a well-established technique. It is part of the influence assessment methods that provide direct and indirect maps of the country's holistic economic system. (van Leeuwen et al., 2005). According to Hewings & Sonis (2009) as an associated model, the input-output tables provide an essential set of economic data to help us understand the nature and strength of interactions between economic sectors.

The application of this methodology has been studied in different social, demographic, and economic settings. Several studies have adopted this analysis model to measure the evolution of the share of the bioeconomy in the national income of regions. For example, Cingiz et al. (2021) estimated the added value of different industries in the Member States of the European Union. Consequently, this sector contributes approximately 45% to the bioeconomy's total value added.
In their study,, they determined the role of the bioeconomy based on input-output matrices, which define the relationships between the different sectors.

Based on the work and methodology developed by ECLAC for this research topic, we will use the supply and demand database tables of the national accounts from certain Latin American and

Caribbean countries to measure the gross value added of the bioeconomy sectors based on the satellite national accounts.

3.5.4. Life Sustainable Cycle Assessment

One methodology for assessing value chain approaches in the bioeconomy is life cycle thinking, which seeks overall system optimization.

Figure 12 shows the graphical scheme of the life cycle sustainability assessment (LCSA), considered the most comprehensive sustainability assessment methodology to date. It assesses all social (S-LCA), environmental (E-LCA), and economic (LCC) negative impacts and benefits to inform decisions towards more sustainable products throughout their life cycle. (Lewandowski, 2017; UNEP & SETAC Life Cycle Initiative, 2011).

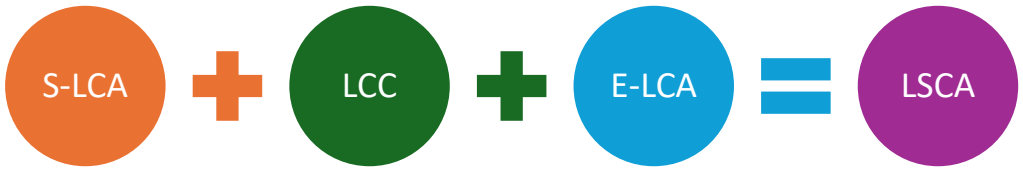

Figure 12. Main components of LCSA.
Source: (UNEP & SETAC Life Cycle Initiative, 2011)

The assessment of the three dimensions of the Life Sustainability Cycle Assessment provides an understanding of the holistic approach to the impacts and risks of value chain production mode.

One of the questions the research aims to address is how the bioeconomy sectors relate to sustainable development; we propose doing a case study in one of the Latin American countries (Ecuador). This study will seek to evaluate through Sustainable Life Cycle Analysis the environmental, economic, and social impact caused by bamboo as a bioeconomy initiative to promote sustainable housing facilities in Ecuador.

4. RESULTS AND DISCUSSION

4.1. Main bioeconomy sectors in Latin America and the Caribbean Region

To answer this first question, we analyzed several global and regional documents that helped us understand potential bioeconomy sectors in the LAC region. Table 3 presents the analysis matrix of documents and the main points that were deducted to determine the type of bioeconomy sectors identified in the documents. Half of the documents clearly distinguish between sectors, while the remaining define the bioeconomy as including all products and services in any economic sector.

Our results show several global, regional, and country-specific documentary definitions of bioeconomy and its main sectors. According to Lewandowski (2017), the concept of the bioeconomy as such has evolved from its early focus on advances in life sciences and biotechnology that have the potential to transform many industrial production processes (Enriquez, 1998; Glick, 1982), to become a significant policy concept in Europe in the early 2000s (European Parliament, 2000).

Since the 2000s, a series of global initiatives, especially in the Northern Cone (USA and Europe), have strengthened these concepts and turned them into governmental plans and strategies (Federal Government of Germany, 2010; Global Bioeconomy Summit 2018, 2018; White House, 2012)focused on the sustainable use of natural resources.

Currently, several countries around the world have bioeconomy-related policies and strategies on which specific projects are done to bust the different economic sectors (International Advisory Council on Global Bioeconomy Global Bioeconomy, 2020). In the case of Latin America and the Caribbean, the global concept of the bioeconomy is applied according to each country's reality, considering that not all have clear plans and strategies to develop this economic model in their territories (Instituto Interamericano de Cooperación para la Agricultura, 2024).

In this research, we have analyzed various institutional documents at the global, regional, and country levels on the concepts and sectors of the bioeconomy in the Latin American and Caribbean region. We identified specific bioeconomy instruments in the form of plans and strategies in six (Costa Rica, Brazil, Argentina, Colombia, Ecuador, Uruguay) of the 33 countries in the region. In this sense FONTAGRO, 2023; Rodríguez et al., 2017a) , noted that several LAC countries do not have explicit and centralized national government strategies dedicated to the bioeconomy; however, some include public policy plans or efforts to develop one or more of the bioeconomy's sectors.

Table 3. Documentary analysis of the bioeconomy sector identified in the LAC region

Document	Time Frame	Institution	Level	Classification of Bioeconomy sectors	
				Identified	Sectors
Costa Rica's National Bioeconomy Strategy (Gobierno Nacional de Costa Rica, 2020)	2020-2030	National Government with five related ministries	Country	No	Concept: All economic sectors to move towards a sustainable economy
The Bioeconomy as a Strategy for Argentinean Development (Buryaile et al., 2012b)	2012	National Government with three related ministries	Country	Yes	a) Production of renewable biological resources and their conversion into food, feed, bio-based products, and bioenergy. This includes agriculture, forestry, fisheries, food, and pulp and fiber production. b) Sectors of the chemical, energy, health, and drug production industries.
Colombia's national bioeconomy strategy(Gobierno de Colombia, 2020)	2020	National Government with 14 related institutions	Country	Yes	a) Food and beverages b) Energy c) Tourism d) Health e) Chemicals f) Agriculture
Action Plan for Science, Technology, and Innovation in the Bioeconomy of Brazil (Ministério da Ciência & Centro de Gestão e Estudos Estratégicos, 2018)	2018	National Government with eight related institutions	Country	Yes	a) Agriculture b) Food sector, c) Materials d) Chemical e) Fuels and energy.
Building a Bioeconomy Collective for Mexico (BIOFIN & PNUD, 2021)	2021	National Government and United Nations	Country	Yes	a) Agriculture b) Forestry, c) Tourism d) Fishing and aquaculture e) Food sector
Uruguayan strategy for a circular and sustainable bioeconomy: challenges in promoting science, technology, and innovation (BIOFIN & PNUD, 2021)	2017	National Government with two related institutions and international support	Country	No	Concept: Bioeconomy is a paradigm of productive development that cuts across all sectors of the economy.
Design of a roadmap for the construction of a national bioeconomy strategy and pilot plan for the Paraguayan Chaco (Productiva Comunicación & Marketing, 2023)	2023	Ministry of Industry and Trade (MIC) and the Inter-American Institute for Cooperation on Agriculture (IICA)	Country	Yes	a) biomass production, b) biofuels, c) bio energies, d)biomaterials and e) valorisation of by-products and waste

Bioeconomy White Paper of Ecuador (Ministerio del Ambiente, 2024)	2024	National Government with two related institutions and international support	Country	No	Concept: Bioeconomy in the national context, Ecuador has transformed its productive structure, promoting innovation, sustainability, and responsible use of biological resources.
Plurinational Policy and Strategy for the Integral and Sustainable Management of Biodiversity in Bolivia (IICA, 2019c)	2019	Ministry of Productive Development and Plural Economy and Ministry of Agriculture	Country	No	Concept: knowledge-intensive use of resources, processes, technologies, and biological principles for the sustainable production of goods and services.
The bioeconomy as a strategy to strengthen MERCOSUR integration (Instituto Interamericano de Cooperación para la Agricultura (IICA), 2022)	2022	Inter-American Institute for Cooperation on Agriculture (IICA)	Regional (Americas)	Yes	a) Maize (and other cereals) and cassava chains, production of bioenergy up to bioplastics; b) Bioenergy and bioplastics chains bioplastics; c) Oilseeds, biodiesel, up to the production of high-quality flours and bioproducts; d) Sugar cane by-products, bioenergy, bio inputs, up to green chemistry; e) Beef, tallow, up to production of biofuels and bioproducts; e) Forestry, up to production of biofuels and bioproducts; f) Forestry, up to the production of bioenergy, bioproducts, and bio inputs; g) Biodiversity, products and services.
The potential of the bioeconomy to transform food systems (Inter-American Institute for Cooperation on Agriculture (IICA), 2021)	2021	Inter-American Institute for Cooperation on Agriculture (IICA)	Regional (Americas)	No	Concept: production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation to provide sustainable solutions (information, products, processes, and services) within and across all economic sectors and enable a transformation to a sustainable economy
Making the Bioeconomy Visible: Methodological Guide for the Estimation of the Bioeconomy Satellite Account in Latin America and the Caribbean: the Case of Uruguay (Instituto Interamericano de Cooperación para la Agricultura (IICA), 2021)	2021	National Government with two related institutions and international support	Country	No	Concept: All sectors of the economy that add value to the products and/or bio-based activities in each branch of production.
Bioeconomy: A sustainable development strategy (Chavarría et al., 2020)	2020	Inter-American Institute for Cooperation on Agriculture (IICA) and International Food Policy Research Institute	Regional (Americas)	No	Concept: knowledge-intensive use of biological resources for the production of products and services across all sectors of the economy

Bioeconomy Status and Outlook Report for Latin America and the Caribbean (Instituto Interamericano de Cooperación para la Agricultura (IICA), 2024)	2024	Sixteen International Institutions	Regional (Americas)	No	Concept: knowledge-intensive use of biological resources, processes, technologies, and principles for the sustainable production of goods and services in all sectors of the economy
Global Bioeconomy Policy Report (IV)(International Advisory Council on Global Bioeconomy, 2020)	2020	International Advisory Council on Global Bioeconomy	Global	Yes	a) Traditional bioeconomy: agriculture, forestry, fisheries and aquaculture. b) Related processing and service industries: food, paper, textiles, building, construction, chemistry, and bio-pharma
The Bioeconomy 2030(OECD, 2009)	2009	Organization for Economic Cooperation and Development (OECD)	Global	No	Concept: "*The use of advanced knowledge of genes and complex cell processes to develop new processes and products, the use of renewable biomass and efficient bioprocesses to support sustainable production, and the integration of biotechnology knowledge and applications across sectors"*
Policy Brief of Sustainable Bioeconomy and FAO (FAO, 2022)	2022	Food and Agriculture Organization (FAO)	Global	No	Concept: "*The combination of bioeconomy and digitalization is often seen as a major driver of the transformation of productive sectors."*
EU Bioeconomy Strategy Progress Report(European Commission, 2022)	2022	European Commission	Regional EU	Yes	All sectors and systems that rely on biological resources (animals, plants, micro-organisms, derived biomass, organic waste), their functions, and principles.
Safeguarding the Bioeconomy (U.S. bioeconomy)(National Academies of Sciences, 2020)	2020	National Academies Press (US)	Regional US	Yes	Sectors driven by research and innovation in the life sciences and biotechnology. These included Agriculture Area (biotechnology inputs), Biomedicine, Bio Industries, and Cross-Cutting Tools, Kits, and Services.
Bioeconomy and Production Development Program(IICA, 2019a)	2019	Inter-American Institute for Cooperation on Agriculture	Regional (Americas)	No	Concept: *"The bioeconomy is the knowledge-intensive use of biological resources, processes, technologies, and principles for the sustainable production of goods and services in all sectors of the economy."*

The bioeconomy: A new framework for sustainable growth in Latin America (Hodson De Jaramillo et al., 2019b)	2019	Agriculture Research for Development (CIRAD) and IICA	Regional (Americas)	No	Concept: *"Bioeconomy represents a socio-economic model that reduces dependence on fossil resources and promotes the production and intensive use of knowledge about biological resources, processes, and principles for the sustainable supply of goods and services in all economic sectors (bioenergy, agricultural, and bio inputs, food, fibers, health products, industrial products, and bioplastics)"*
Bioeconomy in Latin America and the Caribbean Global and regional context and perspective(Rodríguez et al., 2017a)	2017	Economic Commission for Latin America and the Caribbean (ECLAC)	Regional (Americas)	Yes	a) Commodity bioeconomy: products directly derived from the primary bio-based sectors (agriculture and agro-industry; fisheries, aquaculture and by-products; forestry products and wood industry); (b) Commodity value-added bioeconomy: products with some degree of processing, derived from primary bio-based sectors (agriculture, fisheries (food industry; wood pulp and paper industry; natural fiber-based textiles and leather products; biodiesel; bioethanol and other alcohols; solid bioenergy); c) High value-added bioeconomy, manufacturing sectors based on bio-based raw materials (bio-based chemicals; bio-based pharmaceuticals; bioplastics; and bio-based perfumes and cosmetics); d) Non-bioeconomy: Mineral and fossil economy, products derived from mining and fossil-based sectors
Satellite accounts bioeconomy in 13 countries in Latin America and the Caribbean (Vargas et al., 2023)	2023	Economic Commission for Latin America and the Caribbean (ECLAC)	Regional (Americas)	Yes	a) Characteristic activities of the bioeconomy; b) Extended characteristic activities of the bioeconomy; c) Non-characteristic activities of the bioeconomy;

Based on the above instruments, the latest bioeconomy definition of the (GBS, 2018) and the potential of natural resources (water, soil, forests) as well as biodiversity in the region (Interamerican Institute for Agriculture Cooperation, 2019; Sasson & Malpica, 2018), we will base the classification of the bioeconomy sectors on four main categories: a) primary sector bioeconomy, b) primary sector value-added bioeconomy, c) high value-added bioeconomy, and d) service bioeconomy. Figure 13 summarizes each of these categories.

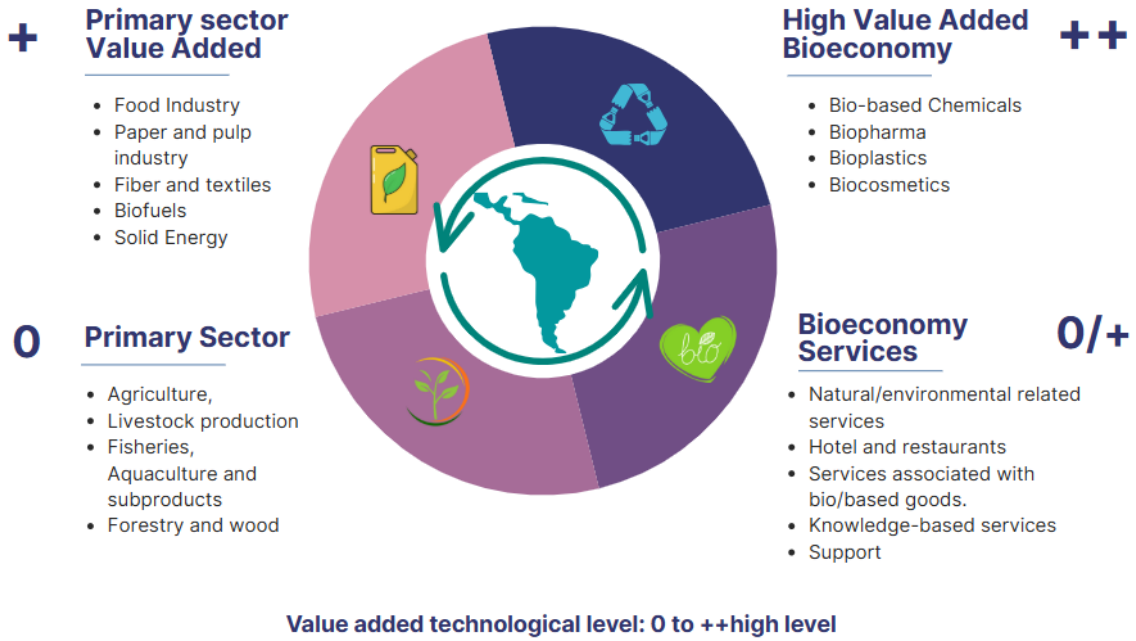

Figure 13. Classification of Bioeconomy sectors for LAC
Source: own construction based on Table 1 data sources and studies of (Rodríguez et al., 2017a; Ronzon et al., 2022)

In addition to the empirical classification shown in the figure above, three key concepts cut across these sectors. Biomass is essential for all these sectors, including biotechnology, which can be pronounced depending on the sector and its sustainability impact.

a) Primary sectors: It considers those sectors of the bioeconomy that use and produce 100% biomass, such as agriculture, forestry, aquaculture, and fisheries.

b) Primary sector value added: Sectors that use biomass from the primary sector and transform it into bioproducts with a certain level of technology (basic or medium, depending on the sector). These sectors include the timber industry, food industry, biofuels, pulp and paper, and solid fuels.

c) High-value-added sector: This category includes sectors that use primary resources and have an elevated level of technology in producing bio-based products. These sectors include biopharmaceuticals, bioplastics, biocosmetics, and bio-based chemicals.

d) Bioeconomy services: those services that use inputs from sectors integral to the bioeconomy, as described above. These include those related to nature/environment, biobased goods, knowledge-based, and support services.

In the same way, the previous figure shows the levels of technology applied in each of the sectors. Where 0 means low level of technology incorporated in the subsectors and ++ means the maximum level of technology applied. The primary sector has a low level of technology incorporation, as well as the bioservices. While the value added sectors have different levels of technology incorporated according to the type of subsector.

In this context, according to Sillanpää & Ncibi (2017), the problem in determining the bioeconomy sectors is the multidimensional concept of bioeconomy, which depends on who defines it. In many of the cases at the regional level, there is no breakdown of which sectors specifically belong to the bioeconomy as it is generalized as the sustainable production of goods and services in all sectors of the economy (Correa et al., 2022; IICA, 2019b; Kefeli & Silva Carrazone, 2017). In other LAC countries, they focus on the production of renewable biological resources and their conversion into bio-based products, bioenergy, biochemicals, and biomaterials, emphasizing the importance of value-added through biotechnology (Buryaile et al., 2012a; Correa et al., 2022; Francisco De Oliveira et al., 2018; Gobierno de Colombia, 2020).

To reinforce the classification of the abovementioned bio-economy sectors, we have carried out a bibliometric analysis of the most important scientific publications related to these sectors in the Latin American and Caribbean region from 2000 until January 2024.

The search yielded 9620 publications, with an average cited per document 16.95. Among the top ten countries that have generated research in this database are Brazil, the United States, Mexico, Argentina, Chile, Colombia, the United Kingdom, Spain, Germany, and Ecuador, most of them from the Latin America and Caribbean region.

In the cluster analysis, we can identify six groups in which the keywords of the documents under analysis are grouped. Table 4 details the keywords relayed to the bio-economy sectors identified in the region. In each cluster is highlighted the key terms and their link strength of connexion. And in the last column the transversal terms related to all the sectors identified.

Table 4. Keyword analysis of the bioeconomy sectors identified within the clusters

Primary sectors			**Primary sector** value-added			**High Value-Added sector**			**Bioeconomy services**			**Transversal concepts related to bioeconomy sectors**
Number of the Cluster	**Keyword related**	**Link strength**	**Number of the Cluster**	**Keyword related**	**Link strength**	**Number of the Cluster**	**Keyword related**	**Link strength**	**Number of the Cluster**	**Keyword related**	**Link strength**	
1	Agricultural identification	96	2	Biodiesel	555	2	Chemistry composition	77	1	Biodiversity conservation	128	* Biomass * Sustainability * Biotechnology * Natural Resources * Climate mitigation * Land use * Impacts * Global warming * Environmental impact * Carbon sequestration * By-products * Co2 emission * Co-generation * Energy security * Eco-efficiency * Footprint * Life Cycle Assessment * Public Policies * Recycling * Incentives and Taxation * Economic development *Food security * Income Equality * Cleaner production * REDD * Gender Equality * Water and soil sources
	Agroforestry	104		2nd generation ethanol	59					Ecosystem services	215	
	Aquaculture	409		Bioenergy	261					Environmental services	102	
	Fisheries	251		Bioethanol	343					Sustainable tourism	41	
	Biodiversity	745		Biofuels	300				4	Environmental management	80	
	Livestock production	299		Biogas	163							
	Forest	615		Biorefineries	62					Information technology	66	
	Production systems	53		Construction Industry	47		Hydrogen production	56				
	Remote sensing	93		Electric vehicles	92					Knowledge transfer	120	
	Sustainable agriculture	78		Future fuels	296							
	Farming systems	70		Lignocellulosic biomass	65					Research and Development	69	
3	Horticulture	49		Renewable energy	311							
	Agricultural productivity sector	100	3	Energy sector	67					Technology transfer	115	
4	Timber sector											
5	Agriculture	526										
	Agroecology	110							5	Technology adoption	58	
	Family farming	52										
	Organic agriculture	37										

Source: Authors construction

Keywords directly related to the primary sector of the bioeconomy, including traditional production activities related to agriculture, livestock, aquaculture, and fisheries, are identified in clusters 1, 3, 4, and 5. Clusters 2 and 3 describe concepts related to the second sector of the bioeconomy, which adds value to the primary sector and mainly includes activities associated with producing biofuels and renewable energy. For the third sector of the bioeconomy, the two cluster stands out with two activities related to the production of chemicals and hydrogen. Finally, important activities related to tourism, research and development, environmental services, and others stand out in the service sector of bioeconomy clusters 1, 4, and 5.

The cross-cutting themes highlight the key concepts described above directly related to the identified bioeconomy sectors (biomass, biotechnology, and sustainability). We will also highlight those of dominant importance for developing the bioeconomy in the region, such as using and managing available natural resources, environmental impacts, economic development, food security, gender, and income equity.

In Figure 14, we can see the graphical representation of the 6 clusters identified. Each color indicates the number of clusters and their grouping of words. The network that connects them is the link between the terms, also called link strength, as shown in Table 1. The first cluster in red consists of 245 terms, the second of 216 (green), the third of 213 (light blue), the fourth of 192 (light yellow), the fifth of 129 (purple), and the sixth of less than 10 terms.

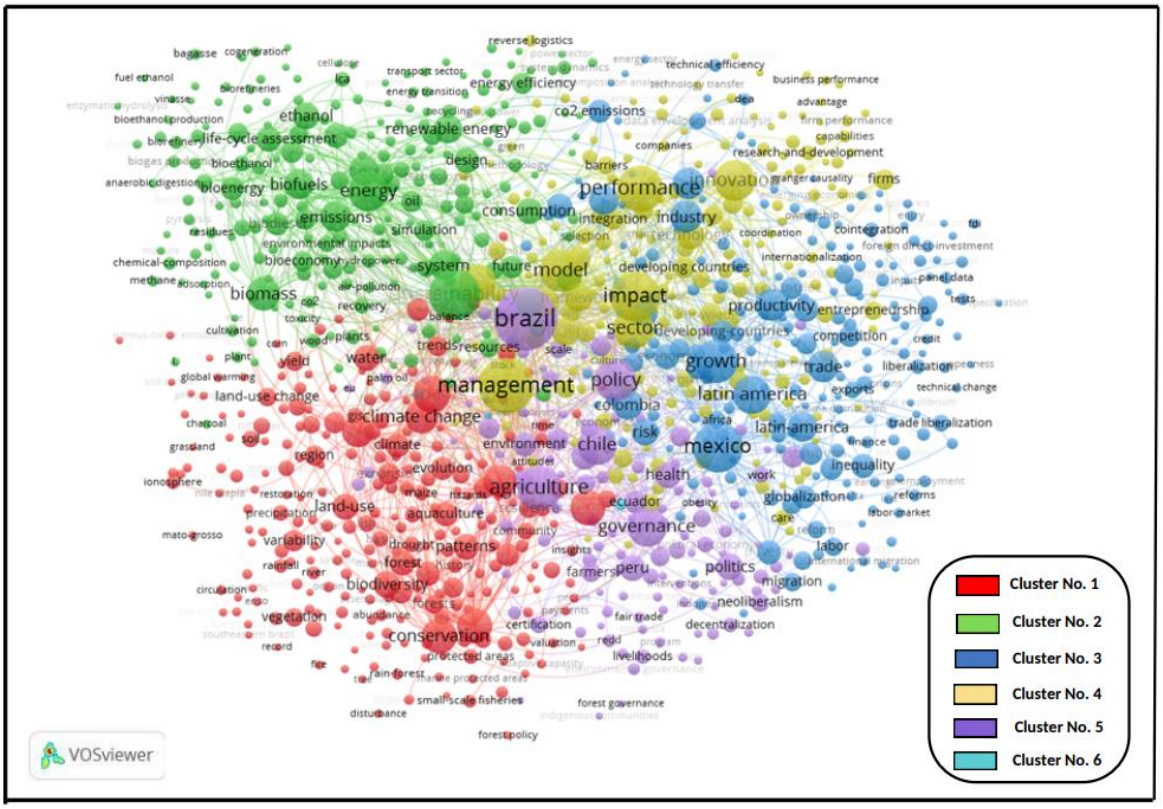

Figure 14. Cluster representation of the corpus analyzed
Source: own construction based on VOSviewer software analysis of the corpus

The first cluster (red) concentrates all the terms related to the environmental aspects of the bioeconomy sectors' production. The most relevant terms are biodiversity, ecosystems, land use change, restoration, sustainable practices, and resource management.

In the green second cluster, we find terms specifically related to the classification of the bioeconomy sectors in the region. The key terms are related to the subsectors of each identified sector and the inputs used by these sectors to produce goods and services. The third cluster (blue colour) specifies terms related to the socio-economic aspects of the identified bioeconomy sectors. Relevant terms include productivity, globalization, trade and labor, and competition.

Cluster four (yellow) is related to the impacts and performance of the bioeconomy sectors. The main terms are knowledge management, organizational performance, business models, integration, and sustainability. Cluster five (purple) is related to the region's primary agricultural sector and rural development. In this cluster, we find key terms such as governance, livelihoods, farmers, participation, fair trade and environment. Finally, the last light blue cluster reflects terms related to circular economy such as resource reuse, waste management, water footprint and collection.

Figure 15 shows the primary trend themes in the database analysis for the region's bio-economy sectors. Among these, we can highlight themes related to bioprospecting, such as medicinal plants, rainforests, and species richness. Renewable energy terms such as neutral winds, electric fields, and power generation can also be seen. In the socio-economic aspects of the bioeconomy, we can find topics such as productivity growth, globalization, economic valuation, unemployment, and gender equality.

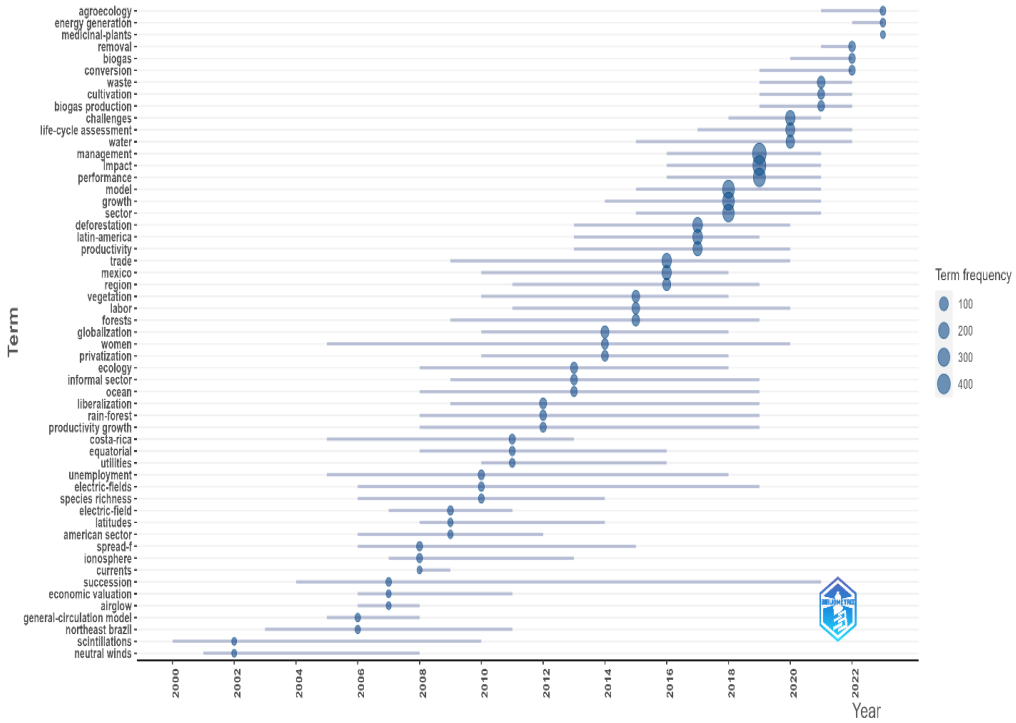

Figure 15. Trend topic analysis of the corpus analyzed
Source: own construction based on R software analysis of the corpus

Our findings are consistent with Ordoñez Olivo & Lakner (2023b) bibliometric analysis, which showes that bioeconomic sectors established in Latin America are focused on primary and primary

value-added sectors such as agriculture and biofuels, with Brazil and Argentina as leaders. In the same vein Perea Mosquera et al. (2021) the bioeconomy's importance in LAC is underlined in the agricultural and agro-industrial sectors (primary sector) as an alternative for growth with emissions decoupling and economic advance.

To complete the analysis of this first part of the findings, which is the identification of the bio-economy sectors in the region, we have formulated a series of interviews with key actors in the region at the institutional, academic, and trade union levels. The following is a presentation of the most relevant extracts from the interviews and an analysis of the information gathered.

The type of interview chosen for the research was semi-structured, for which a guide of questions was developed to allow the respondents to give their points of view on the subject being interviewed. The respondents were selected according to their level of expertise and the institutional scope of their work on the bioeconomy in the region. The primary purpose of this type of expert interview was to obtain systematic information that would complement the findings of the previous sections of this first part of the study.

The first interviewee was Dr Hugo Chavarria, Director of the Hemispheric Innovation and Bioeconomy Program of the Inter-American Institute of Agriculture (a regional body whose scope of action covers Latin America and the Caribbean). He was asked about the main sectors of the bioeconomy in the region and their importance for the economic development of the countries. The transcript of the interview can be found in Annex 1.

The second interviewee was Eng. Augustin Torroba, biofuels specialist at the Secretariat of the Latin American and Caribbean Biofuels Coalition. He was asked about the importance of the biofuels sector in the region, the sustainability concepts involved in biofuels, and the role of the Secretariat in the institutional policies of the countries in the region. The transcript of the interview can be found in Annex 2.

The third interviewee was Dr. Sandra Sharry, the second board member at the Network of Biotechnology Laboratories for Latin America and the Caribbean. She was asked about the research centers' role in developing the region's bioeconomy and the main initiatives currently investigated in this area. The transcript of the interview can be found in Annex 3.

The fourth interviewee was Dr Rafael Anta, the Inter-American Development Bank's science, technology, and innovation specialist. He was asked about the potential of the bio-economy for local development in the Latin American and Caribbean region and how to make bio-economy programs and projects sustainable over time. The transcript of the interview is available in Annex 4.

Finally, we interviewed Dr Monica Trujillo to get an idea of an international research institute. She is a Research Fellow at the Stockholm Environment Institute, which works globally in different regions to develop bioeconomy projects. We asked her about the role of researchers and research institutes in developing these bioeconomy initiatives and what actions or projects the Institute is developing to promote the bioeconomy in the region. The transcript of the interview is available in Annex 5.

The bioeconomy has long existed for Dr Anta but has not been labelled as such. Bioeconomy refers to activities using renewable bio-based resources with significant untapped potential. However, the bioeconomy's economic importance in the region is minimal, even though no standardized regional or national account system exists to measure it.

According to Dr Chavarria, the bioeconomy must have four essential characteristics: (a) it must be based on biological resources; (b) it must incorporate a high degree of science, technology, and innovation; (c) it must add value to products or "integral cracking of biomass"; and (d) it must contribute to environmental sustainability and decarbonization. The other four interviewees share the same considerations and point out the importance of incorporating additional value added to biological resources into the bioeconomy concept.

To complement this statement, Dr Sharry pointed out three different approaches to the bioeconomy: a) the biotech approach, b) the ecological approach based on biological diversity, and c) the approach based on biomass production. In this sense, some countries, such as Argentina and Brazil, can move in any of these directions, as they have considerable biodiversity and are well-developed in biotechnology. The path is centered on biodiversity for others, such as Ecuador, Colombia, and Costa Rica. There is also an important distinction between low-tech and high-tech bio-economies. In Latin America and the Caribbean, there are low-tech countries and others with high and low technology, such as Argentina and Brazil. It is important to differentiate each country's situation according to its national and local reality to understand its position in the region's bioeconomy.

The majority of respondents agreed on the fundamental premise that the bioeconomy as a concept must have the following essential characteristics: (a) be based on biological resources; (b) involve some degree of science, technology, and innovation; (c) add value to biomass; and (d) contribute to environmental sustainability and decarbonization. These assumptions are also referred to by Cristóbal et al. (2016); Faulkner et al. (2024) who point out that the bioeconomy aims to address the complex challenges of economic transition and combating climate change sustainably and equitably. Always considering transforming basic knowledge and biomass into successful industrial production and agriculture, including food, novel bioproducts, and bioenergy (Aguilar et al., 2018; Gawel et al., 2019).

In contrast to what respondents identified as the essential components of the bioeconomy sectors, which do not necessarily include the primary sector, this study considered the primary sector to be part of the bioeconomy because it uses and produces 100% biomass and is one of the region's historical and economic pillars. (Dias Avila et al., 2010; Gorenstein & Ortiz, 2018a).

On this basis, two bioeconomy sectors have been well established in LAC for almost 30 years: agricultural biotechnology applications and biofuels. The respondents classified biofuels as one of the most historically significant primary value-added subsectors of the bioeconomy. In this case, the region is one of the most developed worldwide producers (Bailis et al., 2014; OECD and Food and Agriculture Organization of the United Nations, 2021), with leading countries such as Brazil and Argentina (Flexor & Kato, 2017; Vega et al., 2024a).

In the case of biofuels, their importance can be improved. Currently, the biofuels in the fuel mix are 27% in Brazil, 20% in Argentina, and 12% in Colombia. However, this sector could be expanded if these countries supply and produce aviation fuel. Dr. Torroba mentioned that the region is one of the most developed in the world regarding liquid biofuels, such as bioethanol and biodiesel, to underline the importance of biofuels. Bioethanol accounts for 2/3 of production and consumption, and biodiesel for the rest. On the one hand, Latin America has a long tradition of producing biofuels, especially in Brazil, the first country to start with a blend of regular fuel and biofuels in the 1970s with a program called Pro Alcohol. On the other hand, the region is one of the largest exporters of biological raw materials that are transformed into biofuels in different countries. Regarding the innovations being developed in this sector, the region has a large availability of raw materials and highly developed

value chains in oils and alcohols to produce biofuels tailored to the aviation industry. This represents a great opportunity and potential for the Latin American and Caribbean region, as this industry plans to achieve net-zero emissions globally by 2050. To achieve this goal, almost 60% of the reduction in gaseous emissions should come from Sustainable Aviation Fuels (SAF).

The bio-input sector is intermediate, less significant than the biofuel sector, but one that could be crucial in a few years, given the results in some LAC countries. Currently, the region has 20% of the control of the world market of bio-inputs, especially bio-controls, and it is expected that in 10 years, the region will be the largest producer in the world. Around 60-70% of production and consumption is in Brazil, whose competitive advantage is the current regulation of bio-inputs, which is very flexible and efficient. However, other important countries are interested in the sector, such as Nicaragua, which has a national bio-input strategy, or Peru, which plans to build the region's largest bio-input plant. According to FAO (2024); Goulet (2021); Martinelli & Sellare, (2022) the region currently controls 20% of the global market for bio inputs, particularly biocontrols, and it is predicted to become the world's largest producer in the next ten years.

There are sectors with great potential that can be considered as the bioeconomy of the future, which are less developed and without concrete measures to boost them. One is bioproducts derived from local biodiversity (biocosmetics, superfoods derived from insects, etc.). In the ALC region, two countries have bioeconomic strategies, Colombia and Costa Rica; in the case of Colombia, the basis of their strategy is bio-products from the potential of the Amazon resources, national parks, and biodiversity; an example of them is biocosmetics for which the country has created national research institutes to work on these initiatives. These institutions have identified local biodiversity that has commercial value and are developing products with local communities. They are also present in Ecuador, Brazil, Peru, Costa Rica, and other CAL countries. Another sub-sector of the bioeconomy that is less developed but has great potential is the biorefining of waste, for which the necessary technology is not yet fully developed. Today, countries like Costa Rica are working on small initiatives using coffee, orange, cocoa, avocado, and pineapple residues. However, the technology used is inefficient enough to turn these bioindustries into high-impact ones that transform the region's economy.

Both in the bibliometric analysis and as mentioned by one of the interviewees, there is a novel sector called the bioeconomy of the future, which is less developed in the region and lacks concrete measures to promote it, which is bioprospecting to produce high-added value bioproducts from local biodiversity (biocosmetics, superfoods derived from insects, etc.), which have great potential because the entire region is rich in biodiversity. According to Frontiers, (2020); Landon (2007), South America has the most significant biomass diversity, including tropical rainforests, tropical savannas, temperate forests, and other ecosystems. This is an opportunity, particularly given that less than 5% of Amazon plant species have been researched for potential medical advantages.

According to the IICA definition, the services sector only fulfils two of the four conditions of the bioeconomy, as it is still pending to determine the monetary value of this sector that Latin America offers. Some regional entities such as IICA are working on the first steps to enhance the resources used in farms that provide agricultural tourism services. Some countries use bioremediation services for land decontamination by microorganisms that feed on heavy metals and allow the soil to recover and become productive again.

The service sector, in the case of this study, has been included as it represents those services that use inputs from sectors that are integral to the bioeconomy. These embrace services related to

nature/environment, biobased goods, hotels, tourists, and knowledge-based and support services. The inclusion of the service sector as part of the bioeconomy is also acknowledged in the EU definition, which incorporates and interrelates the bioeconomy with: "land and marine ecosystems and the services they provide" (Ronzon & M'Barek, 2018). Furthermore, Leal et al. (2018) state that the service sector presently accounts for 70-80% of national value-added and employment in countries and includes functions inherent in manufacturing, management, accounting, marketing, research and development, legal services, and others (Manyika et al., 2012; Pelli et al., 2017; Sharma & Malaviya, 2023).

Dr. Trujillo concludes that the bioeconomy can be an alternative for the region if the model is based on sustainability, good governance, research and development, and Indigenous communities' existing knowledge. In addition, it can only be considered a positive transformation model for our region if it ensures that the entire bioeconomy sector operates sustainably at all stages of the value chain and provides added value that includes science, technology, and innovation.

4.2. Economically importance of bioeconomy sectors in the region.

To evaluate the importance of the bioeconomy sectors in the region, we use the methodology employed by ECLAC, which considers the demand and supply tables of the system of national accounts. According to Comisión Económica para América Latina y el Caribe (2008) ,those instruments provide a comprehensive conceptual and accounting framework that can be used to create a macroeconomic database suitable for analyzing and evaluating macroeconomic performance.

The System of National Accounts (SNA) is a statistical framework for a country's economy that provides a comprehensive, consistent, and flexible set of macroeconomic accounts for policy formulation, analysis, and research.

We used the Tables of Supply and Use (COU) of this system to analyze the importance of the bioeconomy in the region's countries. This is considered one of the most important matrices of the National Accounts. It integrates and relates the total supply and demand of goods and services in an economy.

The total supply matrix is the structure of the goods and services in the country's economic territory, plus those imported from abroad. The total demand tables are built by the economic agents (companies, government, and households) and by the rest of the world and consist of the acquisition of goods and services to be used as inputs in production, consumption, capital formation, and exports (Equations 1 and 2).

$$Supply = Production + Imports$$

$$Demand = Intermediate\ Consumption + Final\ Consumption + Export$$

Based on the work and methodology developed by ECLAC (Economic Commission for Latin America) in elaborating bioeconomy satellite accounts, the present analysis is settled, considering the availability of uniform data in the countries. Table 5 summarizes the countries selected for the analysis and the years of evaluation.

Table 5. Countries and years considered for the economic analysis of bioeconomy sectors

Country	Availability of supply and demand tables	
	2018	2020
Argentina	X	X
Brazil	X	X
Colombia	X	X
Chile	X	X
Costa Rica	X	X
Ecuador	X	X
El Salvador	X	
Honduras	X	
Mexico	X	
Nicaragua	X	
Peru	X	X

Source: own construction

When selecting the countries, it is important to note that more updated information was only possible to extract from the Availability of Supply and Demand tables, mainly for the 11 countries mentioned for 2018 and, in some of these countries, for 2020. Therefore, the analysis of the following results will consider the mentioned data limitation, which is counted as a restriction for the study.

4.2.1. Classification of the products and activities of bioeconomy in the region

Based on the analysis made in the first chapter of the results and taking into consideration the potential of natural resources (water, soil, forests) as well as biodiversity in the region, we will classify the bioeconomy sectors into four main categories: a) primary sector bioeconomy, b) primary sector value-added bioeconomy, c) high value-added bioeconomy and d) service bioeconomy. (The previous result section explains in more detail the meaning and subsectors considered in each category sector).

To illustrate the classification of products and activities in each country's supply and demand tables. Table 6 shows an example of the classification of products in Brazil in the categories of bioeconomy and non-economy sectors and sub-sectors.

In the case of the bio-economy sectors, the subsectors are divided into four categories, each containing a product classified in the COU matrix in each country under study; this classification is based on the criteria of the author of this research. The same assessment is made for the non-bioeconomy sectors shown in the table below, with six subsectors.
For the activities detailed in the COU matrix, classification has been made only by sector in each category. Table 7 gives an example of the sample country used for clarification and explanation.

Table 6. Sample of the classification of products in the Brazilian COU matrix to determine the bioeconomy and non-bioeconomy sectors and subsectors.

Bioeconomy Sectors			Non- Bioeconomy Sectors		
Sector	**Subsector**	**Product**	**Sector**	**Subsector**	**Product**
Primary	Agriculture	Rice, wheat and other cereals	No bioeconomy	Community Services	Public administration collective services
		Maize grain			Welfare and social assistance services
		Herbaceous cotton, other temporary fibers			Public health
		Sugar cane			Cement, plaster and similar articles
		Soya beans			Construction machinery
		Other temporary crop products			Buildings
		Orange			Infrastructure works
		Coffee beans		Financial and Company Services	Film, music, radio and television services
		Other permanent crops			Telecommunications, pay TV and other related services
		Cattle and other live animals, animal products			Systems development and other information services
		Milk from cows and other animals			Financial intermediation, insurance and pension plans
		Pigs			Rent and real estate services
		Poultry and eggs			Imputed rent
		Forestry and forestry products			Legal, accounting and consulting services
		Fishing and aquaculture (fish, crustaceans and molluscs)			Advertising and other technical services
Primary Value added	Food textiles and leather	Beef and other meat products			Condominium and building services
		Pork meat			Specialized construction services
		Poultry meat			Other administrative services
		Industrialized fish			Surveillance, security and investigation services
		Chilled, sterilized and pasteurized milk			Private healthcare
		Other dairy products			Maintenance of computers, telephones and household objects
		Sugar			Personal services
		Canned fruit, vegetables and fruit juices			Domestic services
		Vegetable and animal oils and fats		Metal, machinery and equipment	Pig iron and ferroalloys
		Processed coffee			Semi-finished products, flat-rolled products, long-rolled products and steel tubes
		Processed rice and rice products			Non-ferrous metal products
		Products derived from wheat, manioc or corn			Steel and non-ferrous metal castings
		Balanced animal feed			Metal products, excl. machinery and equipment
		Other food products			Electronic components
		Beverages			Office machinery and computer equipment
		Yarn and processed textile fibers			Electronic equipment and communications equipment
		Fabrics			Measuring, testing and control equipment, optical and electromedical equipment
		Other textiles			Electrical machinery, appliances and materials
		Articles of clothing			Electrical appliances

		Footwear and leather goods
	Other manufactures	Tobacco products
		Wood products, excluding furniture
		Cellulose
		Paper, cardboard, packaging and paper artefacts
		Furniture
	Biofuels	Gasohol
		Diesel - biodiesel
		Ethanol and other biofuels
Bioeconomy services	Trade, restaurants, hotels, distribution, educational and research services	Water, sewage, recycling and waste management
		Tractors and other agricultural machinery
		Wholesale and retail trade, except motor vehicles
		Hotel and similar accommodation services
		Food services
		Research and development
		Architectural and engineering services
		Non-real estate rentals and management of intellectual property assets
		Public Education
		Private education
		Arts, culture, sport and recreation services
		Employers' organizations, trade unions and other associative services
		Other machinery and mechanical equipment
		Cars, vans and utility vehicles
		Trucks and buses, incl. cabins, bodies and trailers
		Parts and accessories for motor vehicles
		Aircraft, boats and other transportation equipment
		Miscellaneous industrial products
		Maintenance, repair and installation of machinery and equipment
	Mining	Coal
		Non-metallic minerals
		Iron ore
		Non-ferrous metallic minerals
	Other manufactures	Oil, natural gas and support services
		Printing and reproduction services
		Aviation fuels
		Naphtha for petrochemicals
		Other petroleum refining products
		Inorganic chemical products
		Fertilizers
		Organic chemical products
		Resins, elastomers and artificial fibers
		Agricultural pesticides and household disinfectants
		Miscellaneous chemical products
		Paints, varnishes, enamels and lacquers
		Perfumery, soaps and cleaning products
		Pharmaceutical products
		Plastic articles
		Glass, ceramics and other non-metallic mineral products
		Electricity, gas and other utilities
		Books, newspapers and magazines
		Rubber articles
	Trade, distribution services	Trade and repair of vehicles
		Land freight transportation
		Land passenger transportation
		Water transportation
		Air transport
		Storage and auxiliary transport services

Table 7. Sample of the classification of economic activities in the Brazilian COU matrix to determine the bioeconomy and non-bioeconomy sectors.

SECTOR	ECONOMIC ACTIVITIY	SECTOR	ECONOMIC ACTIVITIY
Primary	Agriculture, including agricultural and post-harvest support	No bioeconomy	Manufacture of motor vehicle parts and accessories
	Livestock farming, including support for livestock farming		Manufacture of parts and accessories for motor vehicles
	Forestry production; fisheries and aquaculture		Manufacture of furniture and miscellaneous industrial products
	Slaughter and meat products, including dairy and fishery products		Maintenance, repair, and installation of machinery and equipment
Primary Value added	Manufacture and refining of sugar		Electricity, natural gas, and other public utility services
	Other food products		Construction
	Manufacture of beverage		Trade and repair of motor vehicles and motorbikes
	Manufacture of tobacco products		Land transport
	Manufacture of textile products		Water transport
	Manufacture of wearing apparel and accessories		Air transport
	Manufacture of footwear and leather goods		Storage, support activities for transport and mail
	Manufacture of wood products		Publishing and printing
	Manufacture of pulp, paper, and paper products		Television, radio, cinema, and sound and image recording/editing activities
	Manufacture of biofuels		Telecommunications
	Water, sewage, and waste management		Systems development and other information services
Bioeconomy services	Wholesale and retail trade, except motor vehicles		Financial intermediation, insurance, and private pensions
	Accommodation		Real estate activities
	Food		Legal, accounting, consultancy, and head office activities
	Other professional, scientific, and technical activities		Technical testing/analysis
	Public Education		Non-real estate rentals and management of intellectual property asset
	Private education		Other administrative activities and complementary services
	Artistic, creative, and entertainment activities		Surveillance and security activities
No bioeconomy	Mining of coal and non-metallic minerals		Public administration, defense and social security
	Oil and gas extraction, including support activities		Public health
	Extraction of iron ore, including processing and agglomeration		Private health
	Extraction of non-ferrous metallic minerals, including processing		Membership and other personal services
	Printing and reproduction of engravings		Domestic services
	Oil refining		Production of pig iron/iron alloys, steel, and seamless steel tubes
	Manufacture of organic and inorganic chemicals, resins and elastomers		Non-ferrous metallurgy and metal casting
	Manufacture of pesticides, disinfectants, paints, and miscellaneous chemicals		Manufacture of metal products, except machinery and equipment
	Manufacture of cleaning, cosmetic/perfumery, and personal care products		Manufacture of computer, electronic, and optical equipment
	Manufacture of petrochemical and pharmaceutical products		Manufacture of electrical machinery and equipment
	Manufacture of rubber and plastic products		Manufacture of mechanical machinery and equipment
	Manufacture of non-metallic mineral products		Manufacture of cars, lorries, and buses, except parts

4.2.2. Supply and Demand Tables (COU)

To explain the structure of the matrix of supply and demand (COU) used to determine the economic importance of the bioeconomy in each country, we will break down each table and give an example of the data for Brazil, on which the rest of the countries have been analyzed using the same logic.

The COUs are a set of non-symmetrical matrices that describe the relationship of inter-industrial flows based on the production function levels of each economic sector. They show the availability of goods and services (supply) and the production destination (demand) between the intermediate and final demand vectors sectors.

The supply tables, represented by output at purchaser prices, provide information on the resources of goods and services available in the current year. The columns identify the sectors of activity, which in turn represent the activities based on information on output generated by each activity or industry. Subsequently, the supply matrix also presents the columns of imports and their CIF1/FOB2 adjustment, as well as the vectors to adjust their different valuations, such as trade and transport margins and taxes on goods and services net of subsidies. Valuations of total supply can be at basic prices and producer and purchaser prices, depending on which components are part of the data presentation.

However, since the raw supply tables extracted from each country's national accounts present the complete column structure as described earlier, in this case, to simplify the information and standardize the data presented, we will consider total production (TP), imports (IMP) and total supply (TS) for each country in a base year.

On the other hand, the demand tables provide information on the uses of goods and services at purchaser prices. They show us, in matrix form, the production cost structures of each industry (intermediate use) and, at the same time, contain the use of each product by final destination (private consumption, government consumption, gross fixed capital formation, change in stocks, exports, and statistical discrepancy) in the form of column vectors.

The demand tables in this study only consider total intermediate consumption (TP), exports (EXP), final demand (FD), and total demand (TD), following the same logic as the supply tables.

Table 8 is a sample of the Brazilian supply table for the year 2020, which is an example of how the analysis was carried out in each country. In the columns, we find the activities classified according to bioeconomy and non-bioeconomy categories, followed by the sum of the three main variables to be studied in the supply table. In the rows, we have the cross-values of the production (classified according to sectors and sub-sectors of the bioeconomy and non-bioeconomy categories) generated by each economic activity.

Table 9 presents the sample demand table for Brazil. It follows the same structure as the previous one but provides data on using goods and services at purchaser prices.

Table 8. Sample of the Brazilian Supply Table of 2018 used for the present study (valued at 1,000,000.00 Reais)

Sector	Subsector	Primary bioeconomy	Primary value-added bioeconomy	Bioeconomy services	No bioeconomy	Total production (TP)	Imports (IMP)	Total supply (TS)
Primary bioeconomy	Agriculture	533747	0	264	920	534931	13899	652386
Primary value-added bioeconomy	Other manufactures	42	195732	250	7406	203430	3862	257147
	Food textiles and leather	282707	556208	42764	4664	886343	56197	1455120
	Biofuels	24	74128	662	216403	291217	3466	420466
Bioeconomy services	Trade, restaurants, hotels, distribution, educational and R&D services	1360	9300	1788855	282291	2081806	119411	1315407
No bioeconomy	Mining	270	64	107	107454	107895	16337	146811
	Other manufactures	184	6388	12926	1097417	1116915	232781	1781500
	Construction	6587	15	438	595824	602864	5530	652823
	Metal, machinery, and equipment	231	2692	9517	945215	957655	302501	1761579
	Trade, distribution services	0	169	2894	707927	710990	15510	576797
	Financial and Company Services	140	5249	118792	2648665	2772846	67815	3015575
	Community Services	0	0	0	965084	965084	0	965084
	Total	**825292**	**849945**	**1977469**	**7579270**	**11231976**	**837309**	**13000695**

Source: own construction

Table 9. Sample of the Brazilian Demand Table of 2018 used for the present study (valued at 1,000,000.00 Reais)

Sector	Subsector	Primary bioeconomy	Primary value-added bioeconomy	Bioeconomy services	No bioeconomy	Intermediate consumption (TP)	Exports (EXP)	Final utilization (FD)	Total demand (TD)
Primary bioeconomy	Agriculture	136294	168895	22635	6880	334704	146922	317682	652386
Primary value-added bioeconomy	Other manufactures	6778	37321	23540	92403	160042	38497	97105	257147
	Food textiles and leather	84350	135229	109048	36326	364953	144266	1090167	1455120
	Biofuels	22352	11269	16505	171821	221947	9873	198519	420466
Bioeconomy services	Trade, restaurants, hotels, distribution, educational and R&D services	11316	23550	49124	254829	338819	46480	976588	1315407
No bioeconomy	Mining	711	1363	126	67736	69936	74671	76875	146811
	Other manufactures	147144	78163	89199	952014	1266520	119044	514980	1781500
	Construction	908	6167	3456	155610	166141	14244	486682	652823
	Metal, machinery, and equipment	8859	26526	23888	728299	787572	198314	974007	1761579
	Trade, distribution services	23311	39563	71026	220959	354859	24655	221938	576797
	Financial and company services	29647	69830	323214	972260	1394951	40883	1620624	3015575
	Community services	0	0	0	0	0	0	965084	965084
	Total	**471670**	**597876**	**731761**	**3659137**	**5460444**	**857849**	**7540251**	**13000695**

The results will also show the contribution of the bioeconomy sectors to the countries' Gross Value Added, complementing the previous analysis of the demand and supply table.

The Gross Value Added is the remainder resulting from subtracting intermediate consumption at purchaser prices from output at producer prices (equation 3). The measure is a key indicator of the state of a national total economy as it helps to adjust the Gross Domestic Product (GDP), a key measure of a country's economic performance.

$$\text{Gross Value Added} = \textit{Output} \text{ (at basic prices)} - \textit{Intermediate Consumption} \text{ (at purchase prices)}$$

GVA is fundamental to analyzing the performance of different sectors of the economy, in this case, extrapolating the position of the bioeconomy sectors in the LAC region. GVA is also an essential measure of economic growth, as it reflects the value of the goods and services produced in a country and provides a sectoral analysis that helps determine which sectors need incentives or stimulus and develop specific sectoral policies.

4.2.3. Considerations for the analysis

The self-written Python script was developed and executed for effective and automatic processing of the original raw data that contained supply and demand tables for each country. This program utilizes a Panda package to read tables from the Excel files. To provide the assignment of table columns to a particular economic quantity (primary, no bioeconomy, primary value-added, bioeconomy services, as well as total product, export, import, total offer, final demand, and total demand), corresponding columns were marked manually with a defined code label. Afterward, the original data were grouped and added according to individual code labels and economical products. The adding algorithm also provided subtotal sum values for individual economy sectors and total sum values for the whole economy for each economic quantity.

To analyze the economic importance of the countries' bioeconomy sectors, we calculated each bioeconomy sector's share in the supply and demand tables to have a comparable and uniform unit for all countries. The assessment for the thirteen countries was carried out using 2018 as the base year, and the historical evolution between 2018 and 2020 was only carried out for seven countries, as data was missing for the remaining countries.

4.2.4. Comparison analysis of the economic importance of bioeconomy sectors in the region

In line with the descriptive logic of the previous tables, the following results will present the contribution of the bioeconomy for the eleven countries of the Latin American region in terms of supply, demand, and the percentage of gross value added in the economy as a whole. As described above, the base year chosen was 2018 to standardize the data for all the countries studied. However, as additional information, it was possible to determine the variance between years in the same macroeconomic indicators for eight countries only**.**

Several studies have been developed in different areas using the same methodology to estimate the economic potential of different sectors. For example, Buccellato et al. (2010) ,used supply and demand tables to separately measure the demand components of tourism and the sector's supply industries and

then reconcile them. Another study by Lipiński (2014) it was indicated that these tables provide a detailed picture of production processes, interdependencies in production, the use of goods and services, and the income generated in production.

The criteria for classifying the bioeconomic sectors of products and economic activities in the supply and demand matrices of each country studied was based on the researcher's criteria, considering what was analyzed in the first stage of the results. The term “classification” refers to a system of classes ordered according to a predetermined set of principles and used to organize a set of entities, groups, or classes; the process scheme itself is arbitrary because the criteria used to define classes reflect a single perspective of the domain to the exclusion of all other perspectives (Jacob, 2004).

4.2.4.1. Bioeconomy importance in supply

Figure 16 shows the share of each bioeconomy category in the eleven countries' national production. In general, non-bioeconomy products and activities represent the region's largest share, averaging 61.88%. This is followed by the primary value bioeconomy (15.41%), bioeconomy services (15.4%), and the primary bioeconomy (7.3%), which has the lowest share.
Regarding the bioeconomy sectors, for the primary axis, Nicaragua, Honduras, and Ecuador have the highest representation in the primary sector. Central American countries like El Salvador, Nicaragua, and Honduras have the highest shares for primary value-added. Finally, except for Nicaragua and Honduras, which have the lowest share in the region, the average value for bioeconomy services is almost the same for all countries.

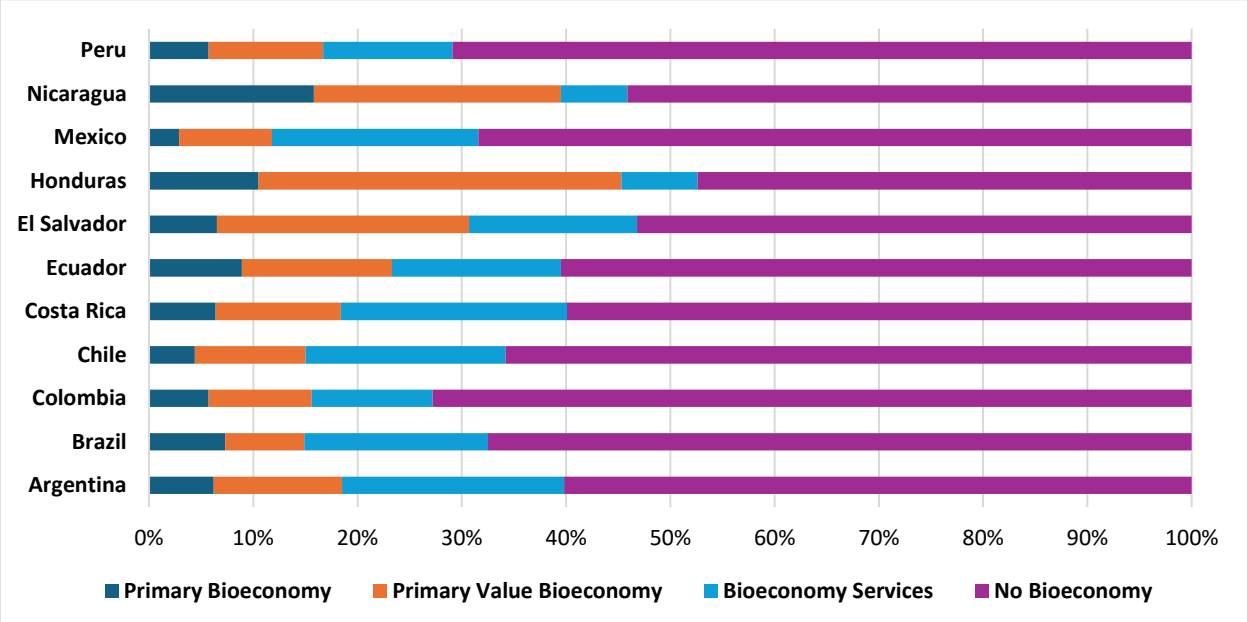

Figure 16. Percentage per bioeconomy category in the domestic production (2018)
Source: own construction

The assumption of the importance of the primary region in the LAC region is also indicated in several studies Barbier (2004); Conroy, Rondinone, De Salvo, & Muñoz (2024); Gorenstein & Ortiz (2018b) who highlights that the primary sector can contribute around 7% of the GDP and 15% of the total employment in the region. According to Hodson de Jaramillo et al. (2014) , there is significant heterogeneity within Latin America, with Central American countries and Mexico participating more

in downstream segments of global value chains. In contrast, South American countries are more active in upstream segments, owing to their specialization in primary industries. Even among the countries that engage in the downstream components of the value chain, some specialize in value chains with low technological content, while others focus on high-technology segments (OECD Development Centre, 2018).

According to Conroy, Rondinone, De Salvo, & Munoz (2024)Brazil, Argentina, and Mexico have the highest gross value of agricultural production, owing largely to their combined 69% of the region's agricultural area, productivity, and the relative concentration of the production basket in higher- or lower-value items.

FAOSTAT shows that the region's small countries have the highest income per hectare, indicating high-value production (FAO STAT, 2024). The latter does not always mean they are more profitable, as they may require higher production costs or more resources and labor. This latter premise is consistent with the results of the current study, which show that Argentina, Brazil, Mexico, and Chile have a lower percentage of primary and primary value-added bioeconomy sectors than Central American countries.

Regarding the share of bioeconomy imports in the countries studied, Figure 17 shows sectoral percentages. The countries with the highest share of imports in the bioeconomy are Nicaragua, Honduras, and Costa Rica. The countries with the lowest share of bioeconomy imports in each sector are Mexico, Ecuador, and Argentina. In the primary value bioeconomy sector, which has the highest share with 29.7% of total bioeconomy imports, the leading countries are the Central American countries (Nicaragua, Honduras, and Salvador), which makes them the most dependent on imports of biological resources. In contrast, the countries with the lowest imports in the same category are Argentina, Brazil and Mexico.

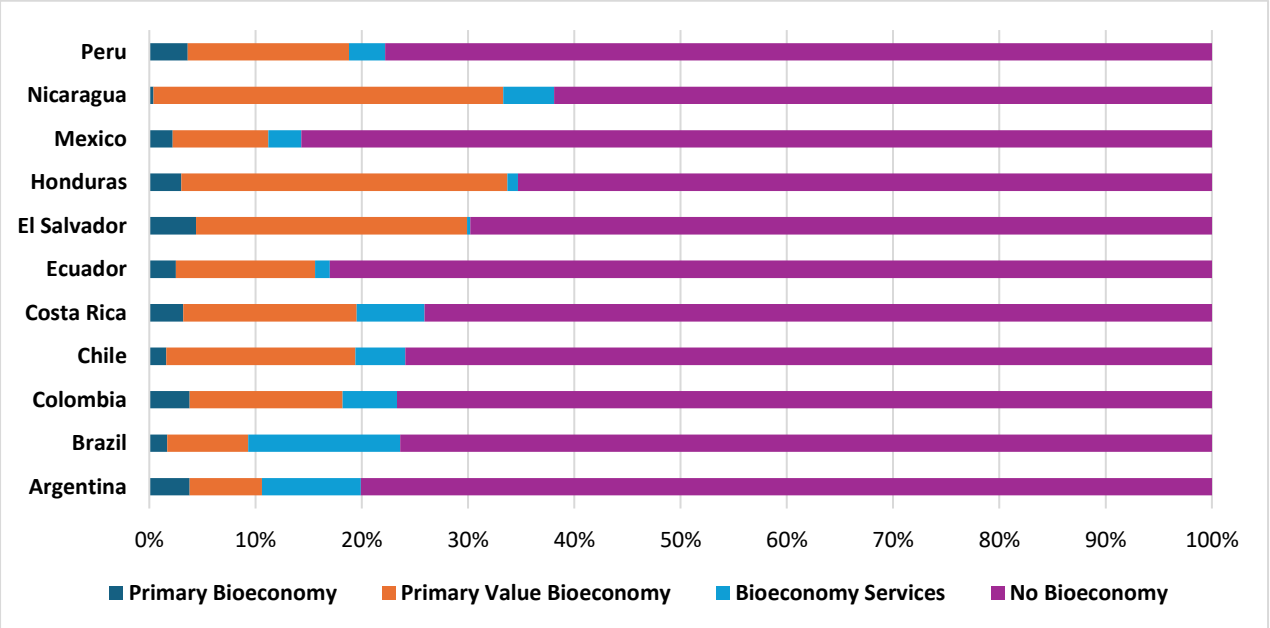

Figure 17. Percentage per bioeconomy category in imports (2018)
Source: own construction

The report "Agricultural Policies in Latin America and the Caribbean 2023" states that several Caribbean and some Central American countries are net food importers, and their agricultural production is not growing significantly compared to other countries in the region (Conroy, Rondinone, De Salvo, & Munoz, 2024) , our findings for Nicaragua and Honduras support the fact that the share of imports in the primary bioeconomy sector is higher in these countries.

Figure 18 shows the percentage difference (positive on the right and damaging on the left) for eight countries to represent the change in total production in the bioeconomy sector between 2018 and 2020. For the non-bioeconomy sector, the difference between negative and positive is almost balanced in several countries, but Argentina and Ecuador have the most significant negative balance. For the bioeconomy sectors of primary production and value-added, the balance is positive in most countries, with a more significant increase in Argentina, Ecuador, and Costa Rica. The balance is negative in all countries for bioeconomy services.

In the case of the supply-side bioeconomy of services, this has a significant representation in all the countries analyzed. Except for Nicaragua and Honduras, which have the lowest share in the region, the average value of bioeconomy services is almost the same for all countries. In this sense D'Amato et al. (2020) point out that the bioeconomy is also characterized by a dependence on provisioning services related more specifically to biomass but also to genetic resources and information-based services. To complement our findings Neill et al. (2020), stress the importance of ensuring that both unrealized and unrecognized services from nature and human actions are included in a holistic of bioeconomic sectors.

In analyzing the percentage difference in the change in total production in the bioeconomy sectors between 2018 and 2020 for 8 of the 11 countries. For primary production and primary value-added, the balance is positive in most countries, with a more significant increase in Argentina, Ecuador, and Costa Rica. For bioeconomy services, the balance is negative in all countries.

It is important to consider that the COVID-19 pandemic occurred during this period. According to OECD-FAO (2021) the case of Latin America and the Caribbean the primary sector was much less affected than others. On average, this sector grew by about 0.46% in 2020, while the region's GDP fell by almost 7%. This increase is reflected in the results of this study: Primary production and primary value-added have a positive balance in most countries. However, it is important to note that, in general, the pandemic had several adverse effects in most countries of the region, such as disruptions in supply chains, increases in food costs, and decreases in income and demand for goods, among others (Pratiwi et al., 2022).

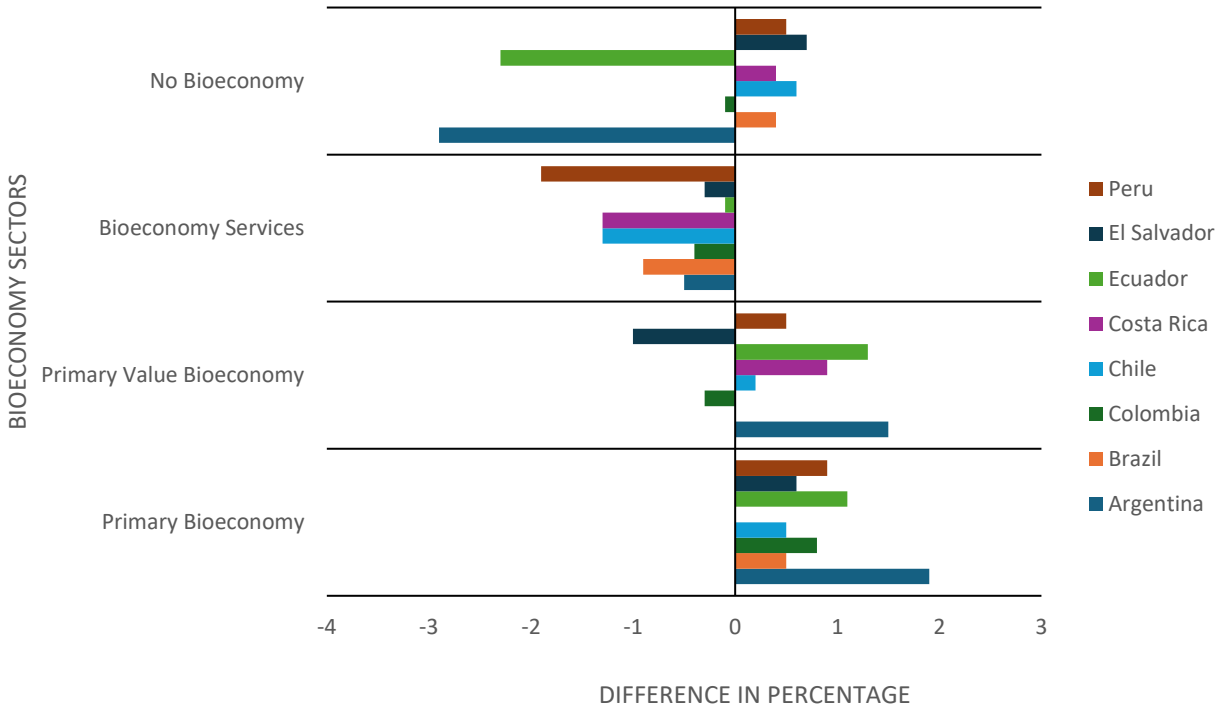

Figure 18. Biannual variation in domestic production of the bioeconomy sectors between 2018 and 2020

Source: own construction

4.2.4.2. Bioeconomy importance in consumption (demand)

On the consumption (demand) side, intermediate use and total exports of the bioeconomy and non-bioeconomy sectors were analyzed. On average, for the eleven countries, non-bioeconomy activities had the highest share, with 60.23% of total consumption, followed by the primary value-added bioeconomy, with 21.77%. Bioeconomy services were in third place, with 11.42%, and the primary bioeconomy was in last place, with 6.58% (Figure 19).

Honduras, El Salvador, and Nicaragua rank first for primary value-added, while Brazil, Mexico, and Colombia rank last. For bioeconomy services, Costa Rica, Chile, and Argentina lead, while Honduras and Nicaragua come last. Finally, Nicaragua, Brazil, and El Salvador are at the top of the list in the primary sector.

Figure 20 shows the share of bioeconomy and non-bioeconomy categories in total exports. For the bioeconomy sectors, the countries with the highest shares are Honduras, El Salvador, and Argentina, while Mexico, Colombia, and Peru are at the bottom of the list. The primary value-added sector has the highest share, with an average of 28.47 percent, followed by the primary sector (10.58 percent) and bioeconomy services (6.23 percent).

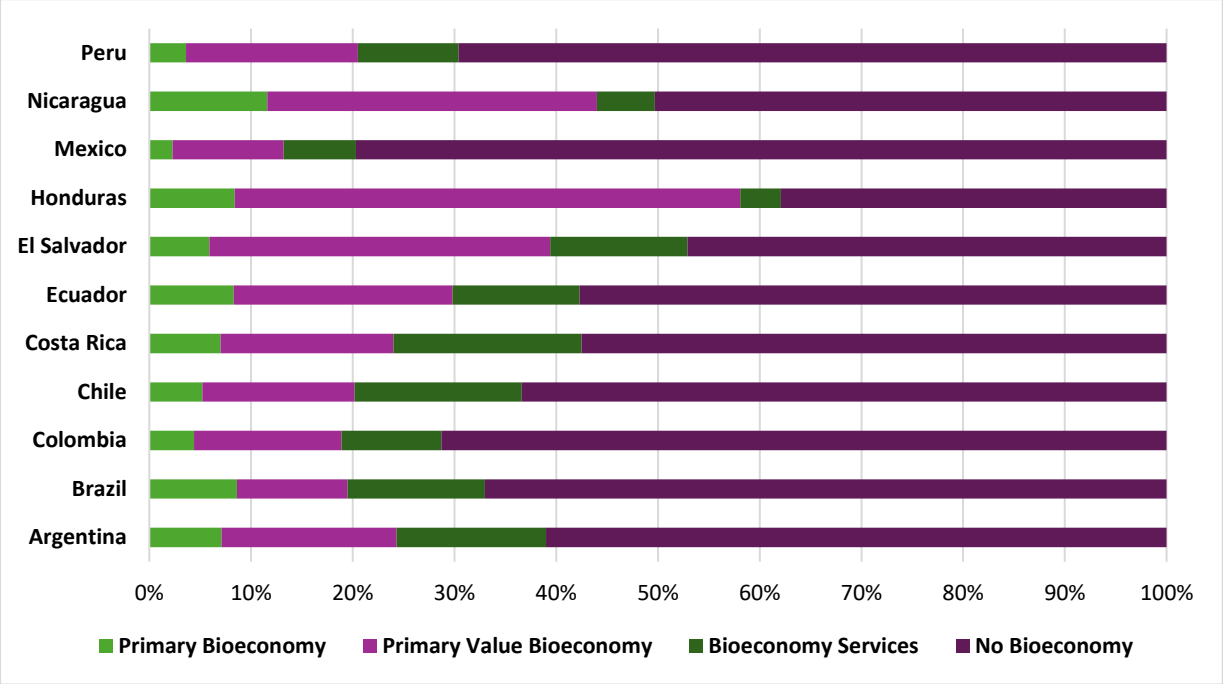

Figure 19. Percentage per bioeconomy category in the intermediate use (2018)
Source: own construction

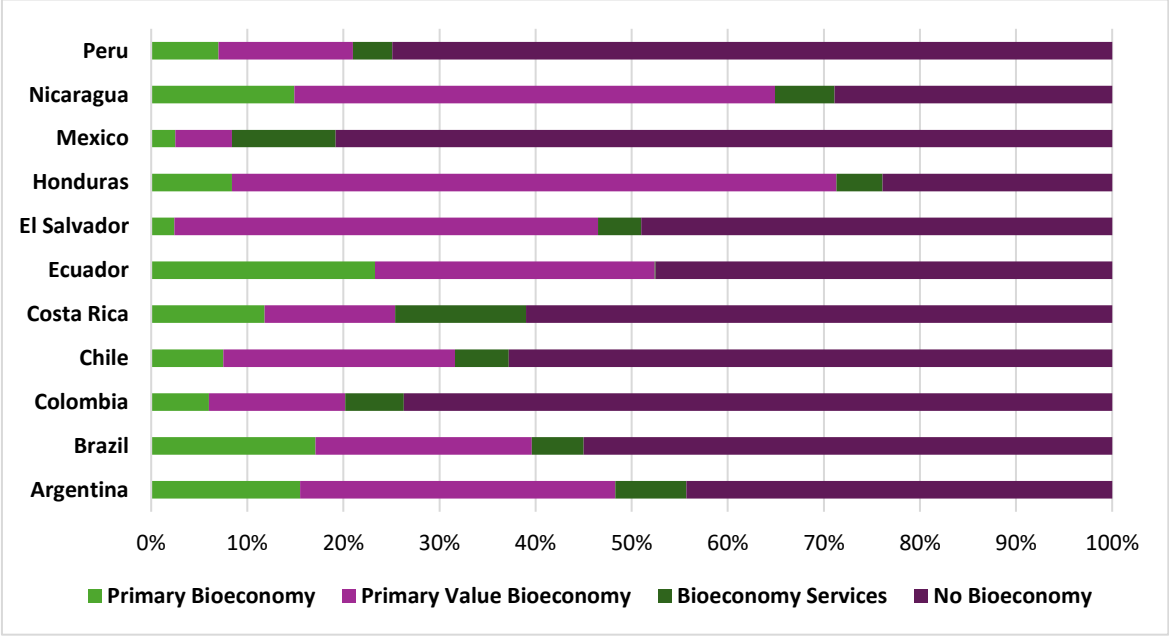

Figure 20. Percentage per bioeconomy category in exports (2018)
Source: own construction

The results described above are in line with those described by Vargas et al. (2023), which analyses the contribution of biological resources in thirteen economies in Latin America and the Caribbean. In this study, the Central American countries are considered to be the ones whose production relies more intensively on a bioeconomic base, increasing their intermediate consumption of these products.

In the case of the share of bioeconomy in total exports, the countries with the highest shares are Honduras, El Salvador, and Argentina, while Mexico, Colombia, and Peru are at the bottom of the

list. These statements are in line with the study by Vargas et al. (2023), which shows similarities in the countries described regarding the majority shares of bioeconomy products and the lower shares. The above-mentioned results can also be linked to the importance of the primary sector in the structure of the exports of the individual countries (Toledo, 2017).

Figure 21 shows the different sectors of the bioeconomy and non-bioeconomy in the Latin American and Caribbean countries assessed in terms of the half-yearly comparison of the change in intermediate use between 2018 and 2020. For the non-bioeconomy and bioeconomy services, the values are negative in most countries. The only exceptions are El Salvador and Colombia, where each sector has a positive value. In the case of the primary and primary value-added sectors, the trend is positive in most countries, except Colombia, in both sectors. Argentina has the highest positive growth rate during this period, followed by Chile and Ecuador**.**

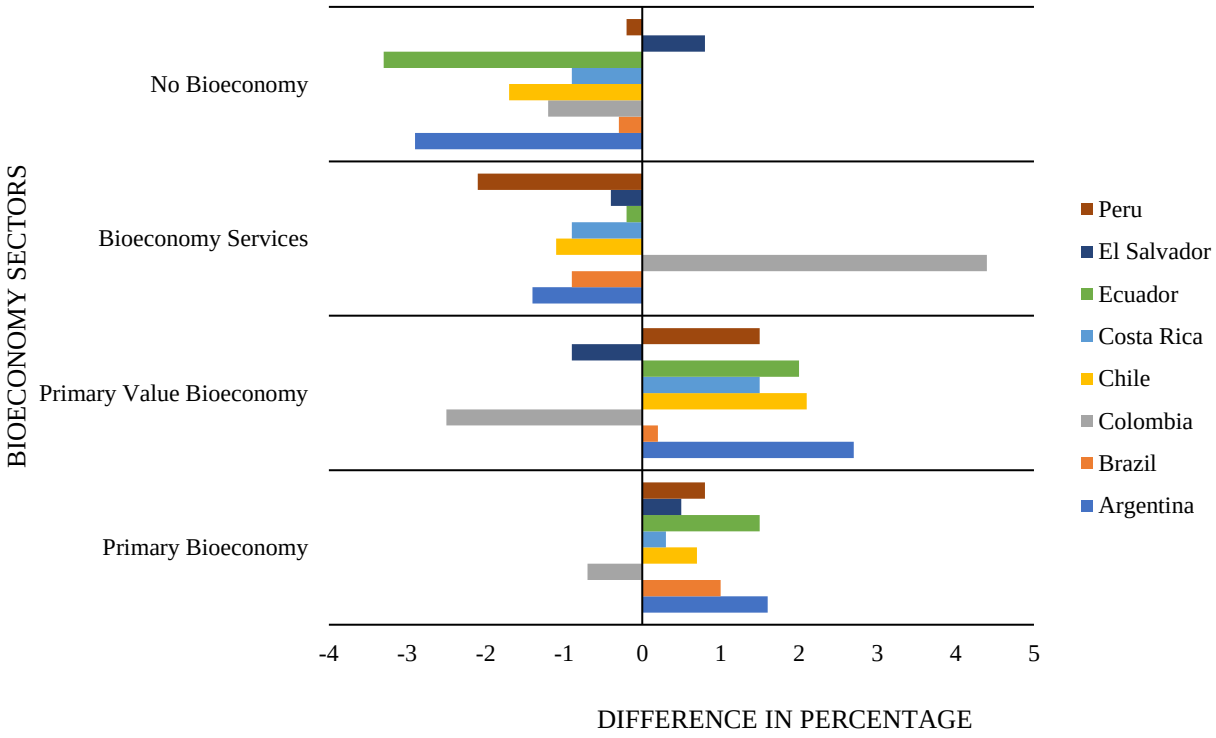

Figure 21. Biannual variation in intermediate use of the bioeconomy sectors between 2018 and 2020
Source: own construction

4.2.4.3. Bioeconomy importance in gross value added

As mentioned above, an important macroeconomic indicator of a country is the gross value added to its economy. Table 10 shows the percentage contribution of the different bioeconomy sectors in the eleven countries under review. As mentioned in the previous sections, no data for 2020 for Honduras, Mexico, and Nicaragua are available. For 2018, in the case of the primary sector, the countries with the highest values are the Central American countries, such as Nicaragua and Honduras, while the countries with the lowest values are Mexico and Chile. For primary value-added, the trend remains the same for the highest countries but changes for the lowest, Brazil and Colombia.

For bioeconomy services, the trend in 2018 is above 19% on average for most countries. The exceptions are Ecuador, Peru, Honduras, and Nicaragua. Overall, the non-bioeconomy sectors account for more than 50% of the total economy in all countries.

The position of some countries differs in 2020 from 2018, as not all countries are analyzed. In the case of primary and primary value-added sectors, the highest percentages are in Colombia, Ecuador, Salvador, and Costa Rica. The trend of countries remains the same as in 2018 in the case of bioeconomy services and non-bioeconomy sectors.

Numerous studies have shown that the region's economic growth trajectory remains in traditional sectors such as forestry, agriculture, primary value-added industries, and, in some nations, biofuel production (Bracco, Calicioglu, Gomez San Juan, et al., 2018b; Leavy et al., 2024; Vázquez-López, 2024). Despite having considerable natural resource endowments, many Latin American countries remain at the bottom of numerous global value chains and world trade primary product value chains, adding little value at the domestic level (Hernández et al., 2014).The aforementioned is related to one of this research's most significant findings, as sectors belonging to high-value-added bioeconomies were not identified in the national accounts of the studied countries.

In Table 11, the percentage change in gross value added in the bioeconomy sectors between 2018 and 2020 is presented and compared. The comparison could only be made for eight countries, as described in the previous sections. Except for Brazil and Costa Rica, the variation is positive for the primary sector, with an average growth of 1.13%. In the case of the value-added primary sector, half of the countries have a positive variation, while the rest have a negative variation. For bioeconomy services, most countries tend to be negative, except Argentina. Most countries, except for Argentina and Ecuador, have seen positive changes in their non-bioeconomic sectors.

Table 10. Contribution of the bioeconomy and non-bioeconomy sectors to the Gross value added in the total economy of the countries (percentage)

Year	Sectors	Argentina	Brazil	Colombia	Chile	Costa Rica	Ecuador	El Salvador	Peru	Honduras	Mexico	Nicaragua
2018	Primary Bioeconomy	5.3	6.13	6.97	3.73	5.83	9.36	7.17	7.49	12.84	3.42	20.61
	Primary Value Bioeconomy	7.8	4.37	5.63	6.55	7.63	8.77	15.26	6.08	18.68	7.25	13.90
	Bioeconomy Services	27.4	21.58	13.27	21.73	24.62	19.16	18.62	14.47	10.90	30.15	7.07
	Total contribution of BES	**40.5**	**32.08**	**25.87**	**32.01**	**38.08**	**37.29**	**41.05**	**28.04**	**42.42**	**40.82**	**41.58**
	No Bioeconomy	59.5	67.92	74.13	67.99	61.92	62.7	58.95	71.95	57.58	59.22	58.42
2020	Primary Bioeconomy	7.51	5.96	9.10	3.92	5.70	10.22	7.66	8.37	n/a	n/a	n/a
	Primary Value Bioeconomy	8.04	4.20	7.10	5.37	8.23	9.90	14.47	6.11	n/a	n/a	n/a
	Bioeconomy Services	27.91	20.87	7.40	20.15	22.88	18.89	18.35	12.63	n/a	n/a	n/a
	Total contribution of BES	**43.46**	**31.03**	**23.6**	**29.44**	**36.81**	**39.01**	**40.48**	**27.11**	**n/a**	**n/a**	**n/a**
	No Bioeconomy	56.54	68.98	76.4	70.57	63.19	60.99	59.53	72.90	n/a	n/a	n/a

Source: own construction

Table 11. Biannual variation of the gross value added in the bioeconomy sectors between 2018 and 2020 (value in percentage)

Sectors	Argentina	Brazil	Colombia	Chile	Costa Rica	Ecuador	El Salvador	Peru
Primary Bioeconomy	2.22	-0.17	2.13	0.19	-0.13	0.85	0.48	0.88
Primary Value Bioeconomy	0.23	-0.17	1.47	-1.19	0.60	1.13	-0.79	0.03
Bioeconomy Services	0.50	-0.72	-5.87	-1.59	-1.74	-0.27	-0.27	-1.85
No Bioeconomy	-2.96	1.06	2.27	2.58	1.27	-1.71	0.58	0.95

Source: own construction

4.2.4.4. Contribution of each subsector to the bioeconomy in the LAC countries evaluated

Figure 22 presents geographical maps showing the percentage contribution of each bioeconomy subsector to help interpret the contribution of the different countries' bioeconomy subsectors in 2018.

In the case of agriculture, Nicaragua and Honduras are the leaders, while Brazil and Chile have the lowest shares. This also reflects these countries' dependence on the primary sector, which makes them more vulnerable, especially in underdeveloped regions like LAC.
For the sub-sector 'Food, textiles and leather,' the average for the region is 11.63%, with the three Central American countries and Ecuador again being the main contributors. In the case of other manufacturing industries, such as cellulose, wood products, tobacco, etc., the countries that contribute the most are Argentina, Chile, Nicaragua, Honduras, and Brazil, while those that contribute the least are Mexico, Costa Rica, and Colombia.

For the biofuel subsector, only Brazil and Colombia include the different products and activities related to biofuels, according to the data obtained from the national accounts of the countries evaluated. For Argentina, despite being one of the leading biodiesel producers worldwide, the national accounts do not include the contribution of the biofuel subsector. Therefore, the data for that country are missing from the chart. For this analysis, Brazil is the region's leading biofuel producer, followed by Colombia.

As regards the Bioeconomy Services Sector, Costa Rica, Ecuador, Colombia, Mexico, and Brazil are the main contributing countries. The above-mentioned countries are known in the region for being very competitive in the world tourism ranking due to their natural attractions, biodiversity, and cultural values. In the other countries, the average percentage contribution is less than 15%, with Nicaragua being the lowest contributor.

	Agriculture	Food, textiles and leather	Other manufactures	Biofuels	Bioeconomy Services
Argentina	6	8	3,9	-	12,8
Brazil	4,8	7,9	1,8	2,6	18,5
Colombia	5,9	7,4	2	1,5	20
Chile	4,3	7,1	3,1	-	15,5
Costa Rica	6,5	9,2	2	-	21,3
Ecuador	7,9	10,9	3,3	-	17,3
El Salvador	6,6	18	4,3	-	8,9
Honduras	9,8	25,2	3	-	8
Mexico	2,8	6,7	2,2	-	17,8
Nicaragua	15,9	19,1	4,4	-	6,39
Peru	5,6	8,5	2,2	-	11,4

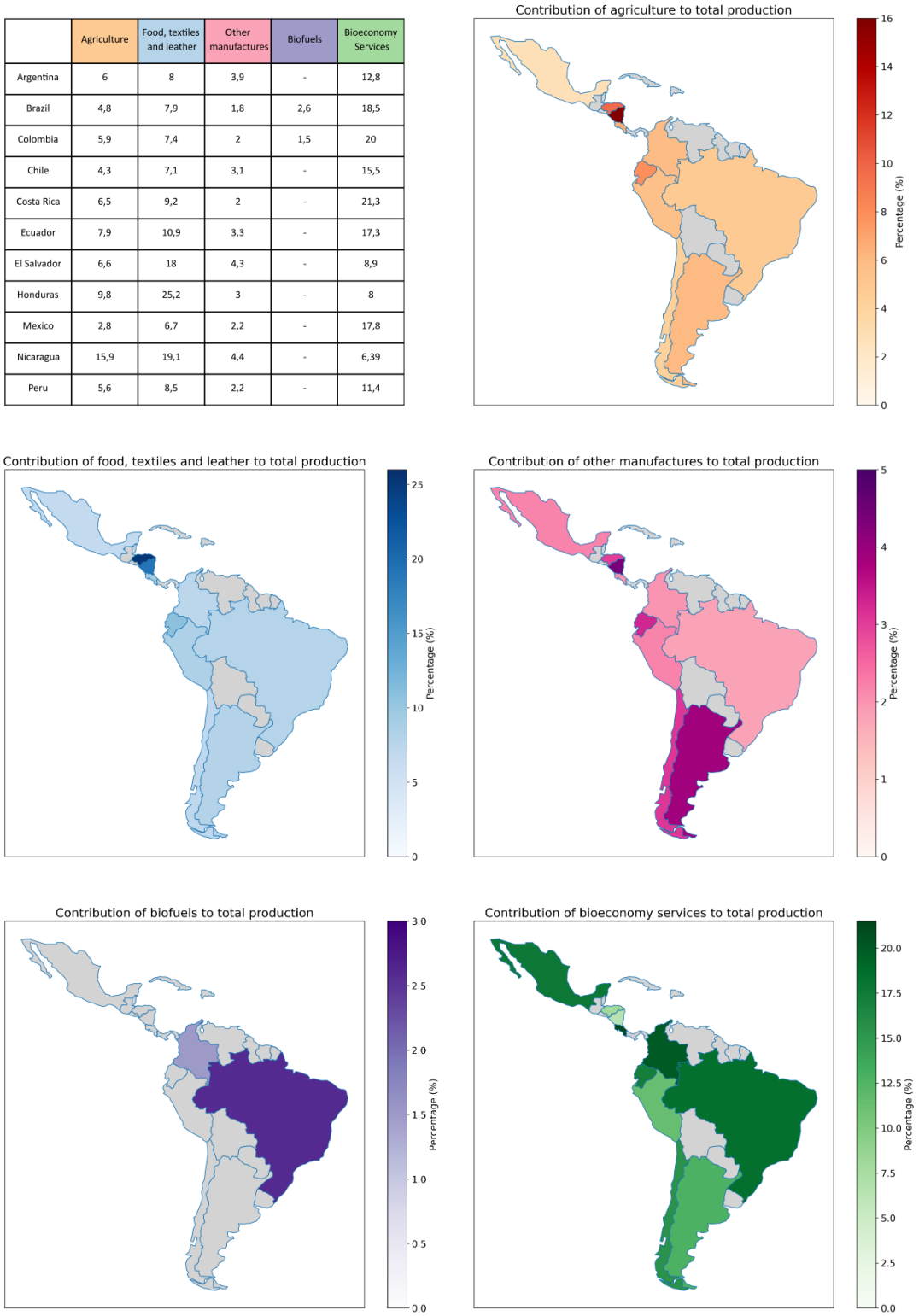

Figure 22. Geographical representation of the contribution of bioeconomy sectors in the LAC studied countries.
Source: own construction

In the case of agriculture, Nicaragua and Honduras are the leaders, while Brazil and Chile are the countries with the lowest shares. This also reflects these countries' dependence on the primary sector, which makes them more vulnerable, especially in underdeveloped regions like LAC. Our findings are consistent with previous research Guasch et al. (2012); Orozco & Padilla Pérez (2023) found that, except for a few countries, the Central American region remains heavily reliant on the primary sector (agriculture is the primary source of exports), with insufficient diversification into manufacturing or agricultural product processing. While Brazil and Chile have substantial primary sectors, they do not contribute the most to their countries' economic balance. These countries' trade balances are primarily concentrated on non-bioeconomic industries like mining and oil (Barraud et al., 2008; Salama, 2020).

In the case of the primary value-added sector, in the sub-sector 'Food, textiles and leather,' the average for the region is 11.63%, with the three Central American countries and Ecuador again being the main contributors. In the case of subsector "other manufacturing industries," such as cellulose, wood products, tobacco, etc., the countries that contribute the most are Argentina, Chile, Nicaragua, Honduras, and Brazil. In contrast, those that contribute the least are Mexico, Costa Rica, and Colombia. In this regard, Brondino et al. (2023); Yamaura et al. (2018) believe that the LAC region retains a pattern of specialization geared toward the export of primary commodities. Other industries in the region with Medium-low technological complexity are often dominated by sectors that perform the initial transformations of natural resources, such as food, textiles, furniture, and oil refining.

For the biofuel subsector in the current research, only Brazil and Colombia include the different products and activities related to biofuels, according to the data obtained from the national accounts of the countries evaluated. For Argentina, despite being one of the leading biodiesel producers worldwide, the national accounts do not include the contribution of the biofuel subsector. Therefore, the data for that country are missing from the chart. For this analysis, Brazil is the region's leading biofuel producer, followed by Colombia. Our findings are consistent with the research of Guerrero-Lemus & Shephard (2017), which reveals that biofuel production in the LAC region is primarily limited to Brazil, Argentina, and, to a lesser extent, Colombia and certain other nations in the region. For Janssen & Rutz, (2011a); Vega et al. (2024b) in the same core countries, most of their biofuel processing capacity is based on the transesterification of vegetable oils from various crops, the most prevalent of which are soybeans and oil palm.

Regarding the Bioeconomy Services Sector, Costa Rica, Ecuador, Colombia, Mexico, and Brazil contribute the most. The above-mentioned countries are known in the region for being very competitive in the world tourism ranking due to their natural attractions, their biodiversity, and their cultural values (INCAE Business School, 2024). In the other countries, the average percentage contribution is less than 15%, with Nicaragua being the lowest contributor. The importance of bioeconomy services is also highlighted by Ahmed (2018), who states that a growing global population requires increased services to meet the needs of sectors such as food, animal feed, fibers for clothing and housing, and so on. A new and more effective bio-economy holistic approach is urgently required to help address these needs in new, more powerful ways.

4.2.5. Main challenges for the development of bioeconomy sectors in the LAC

In this section, the interviews from the first part of the findings will be recapitulated, where five key actors present their main perceptions on the importance of the bioeconomy as a development model for the Latin American region.

For the respondents, the bioeconomy can be an alternative development model for all countries, but the region faces several difficulties in its implementation. For Dr. Chavarria, given that the primary input of the bioeconomy is biomass resources and that the region is one of the most biodiverse, the bioeconomy is the only model in which the region can achieve successful development based on the comparative advantages of the territory. For example, 50% of the world's known biodiversity is in 15% of LAC territory; the region has 25% of the world's forests; 17 of the world's mega-diverse countries are located in LAC countries, among other advantages.

To complete these considerations, Dr. Anta mentions that implementing bioeconomy is a great challenge since the LAC region has always been pointing out of producing and exporting mainly primary products with essential value-added technologies. However, these remarks can represent an opportunity to expand the bioeconomy sectors. For Dr Trujillo, this model must meet the requirements of sustainability, good governance, the integration of research and development, and existing knowledge to ensure that it is sustainable at all stages.

Dr Anta said several key criteria need to be considered regarding sustainability. For example, the limits of the primary biomass that can be harvested without compromising the food security of communities and the biodiversity of ecosystems. In many cases, agricultural biomass leads to converting land to crops that do not belong to the ecosystem and creates other sustainability problems to obtain better economic returns. The third aspect is the definition of areas, species, and production quotas for bio-economic by-products such as biofuels, where the government has a unique role in establishing laws and sanctions for companies that do not comply with the regulations. Finally, in the case of waste, the advantage of the bioeconomy is to create products from waste that minimize its environmental impact. In conclusion, LAC countries must allocate resources to define and apply sustainability criteria within the bioeconomy.

In most of the cases, the interviewers agreed that the main constraints of the region to develop and implement bioeconomy categories are the following:

a) Position of the bioeconomy concepts in the decision-makers in the region: Lack of convincement of the decision makers; Europe has less than 16% of the natural resources in the world (LAC has almost 50%), they give a high relevance to Bioeconomy, while in LAC region we are paying attention to not so relevant topics without consider topics in larger and long scale, since this person in charge of the keys institutions are for short periods without and institutionalist of the policies.

b) There is a lack of specific public policies for the bioeconomy in the region's countries: only a few countries in Latin America and the Caribbean have bioeconomy strategies with clear objectives and budgets to achieve them in the long term. For example, Dr Anta pointed out that some countries, like Argentina, allocate bioeconomy resources to their agricultural strategy. Brazil, for example, does not have any objectives, but it includes resources in its bioeconomy strategy; Uruguay has a strategy, but it is unclear whether it has the budget to

implement it; Mexico is currently preparing a strategy, and Costa Rica has a strategy, but it has economic limitations to implement it.

c) The LAC region cannot take advantage of its capacities: The region has an enormous biological resource that is not exactly well known how to use since most of the countries in the region do not have bioprospection projects.

d) Lack of investment in bioeconomy initiatives: In this case, Dr Sharry points out that there are no human resource constraints for LAC countries, as the region has many capable researchers in all fields. However, the main obstacle to developing a bioeconomy for any country is funding (economic resources). R&D funding in the area has been scarce, and what has been available has been restricted to short-term projects.

e) Regulation and standards for bioeconomy initiatives: In several Latin American countries, regulating chemicals is more straightforward and less bureaucratic than registering bio-based products. For example, registering a biofertilizer can be very slow, and certification is probably impossible because government institutions have no regulations or protocols for applying, evaluating, measuring, or categorizing this product. In conclusion, there is a need for more institutionalization in the regulation and certification of organic products in LAC countries.

f) University research must respond to industry's needs in relation to bio-economy initiatives: Dr Trujillo mentioned that the interface between universities, companies, and research centers is fundamental. However, there is often a need for more coordination and cases where a university supports a company and vice versa. For example, researchers study theories that are not applied in companies' reality. For these synergies to be in place, the role of governments is key in bridging the gap between bio-economy innovation and academia.

4.3. Bioeconomy sectors related to sustainable development

In the last part of the results, we will show the overall impact of the bioeconomy on the SDGs to determine how the sectors relate to sustainable development in Latin America and the Caribbean. We will select some of them to show different analyses and a case study to determine the relationship between the bioeconomy and sustainability.

From the basis of their concepts, both bioeconomy and sustainability have gone hand in hand as they formally seek to use natural resources sustainably. This relationship has been explained over time through scientific research, the growth of significant bioeconomy sectors such as biofuels, and regional or governmental plans in some countries that aim to establish a long-term sustainable bioeconomy model. Biber-Freudenberger et al. (2020), found that bioeconomic developments, such as biofuels and the food and feed sector, have positive sustainability implications at scale. On the other hand Rojas-Serrano et al. (2024) indicate that a sustainable bioeconomy can help to achieve the sustainable development goals of responsible consumption and production, industry, innovation and infrastructure, poverty reduction, social fairness, and environmental protection.

4.3.1. SDG and bioeconomy as a concept

Using the same bibliometric data mentioned in the first part of the results, Figure 23 shows the number of articles related to each sustainable development goal in the entire corpus. The analysis was performed in the Web of Science database based on the keywords established at the beginning. This allowed determining the total number of articles in the corpus and filtering by the relationship of these documents to the SDGs.

Figure 23. Number of articles in the bibliometric corpus that are related to the SDGs
Source: own construction

Numerous studies show the links between the bioeconomy concept and the sustainable development goals. One of these studies (Calicioglu, 2024; Calicioglu & Bogdanski, 2021) suggested that the bioeconomy can provide opportunities to implement the SDGs across sustainability dimensions, especially those related to economic development (SDG 8), food security (SDG 2), and sustainable consumption (SDG 12).

This remark is consistent with our findings, which show the association between the number of bioeconomy scientific publications in the LAC region and the SDGs. The SDG with the highest number of related articles is number 13 (combating climate change), followed in the top three by SDG 15 (sustaining life on Earth) and number 1 (eradicating poverty). Below the descriptive SDGs, important SDGs such as number 9 (innovation and infrastructure), number 8 (good jobs and economic growth), number 3 (good health), and number 2 (zero hunger) have between 1,000 and 710 related articles. The remaining SDGs have a less representative number of related articles, and the only one with no related articles at all is SDG 17 (partnering to achieve the goals). According to Heimann

(2019b) , the SDGs can serve as an adequate sustainability standard for both bioeconomy principles and specific bioeconomy actions

4.3.2. Relationship between the bioeconomy in Latin America and sustainable development of the region

To determine the relationship between the bioeconomy and sustainable development in the LAC region, we will illustrate it through different analyses and a case study related to specific SDGs.

The first two analyses will review secondary data on SDGs 1, 2, and 5 issues. The third analysis will be a case study in a South American country on which we have collected primary and secondary data, using a specific methodology and software to obtain the results. This case study is related to SDGs 9, 11, and 13.

4.3.2.1. SDG 1,2: Food security and bioeconomy sectors

The first analysis determines the relationship between one of the region's bioeconomy sectors (biofuels) and three key food security variables, considering their intrinsic economic, social, and environmental impacts in eight LAC countries (Figure 24).

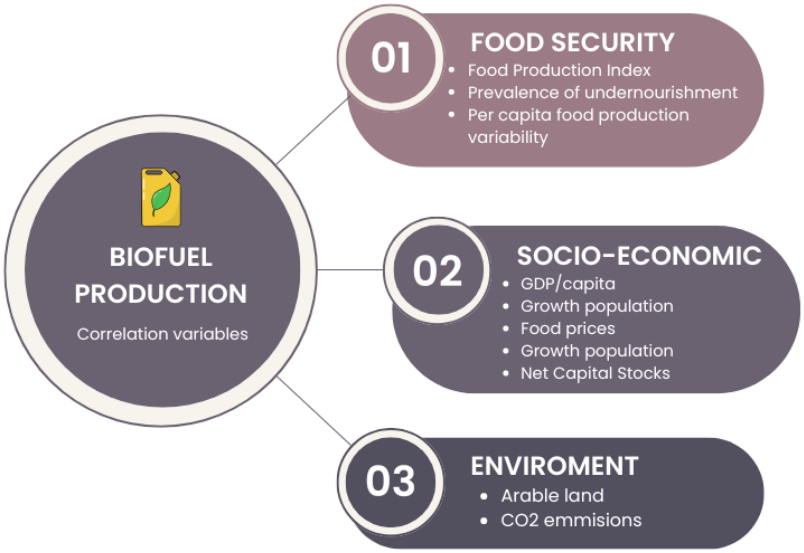

Figure 24. Variables to consider in the analysis.
Source: own construction

To obtain the results, we applied panel data analysis using the following econometric formula involving cross-section data, denoted by the index (i), and a time series, represented by the index (t).

$$\gamma_{i,t} = \alpha_{i,t} + \beta x_{i,t} + e_{i,t}$$

where $x_{i,t}\beta$ Is the matrix of independent variables that we use for this study, which are the food Production Index, the prevalence of undernourishment, per capita food production variability, GDP per capita, arable land food prices, CO2 emissions, net capital stocks, and growth population; in a country I for a period *t*. For our dependent variables $\gamma_{i,t}$ we consider biofuel production in the

countries in which historical information was available. The $\alpha_{i,t}$ indicates the specific effects unobserved in a country and $e_{i,t}$ is the error term.

The analysis uses composite panel data for eight LAC countries (Argentina, Brazil, Chile, Colombia, Mexico, Paraguay, Peru, and Uruguay) from 2007 to 2021. We use this period and these countries because data, particularly on biofuel production, is available for all countries in the region.

The variables described above were selected through an analysis of the empirical literature and extracted from different datasets, including the Organization for Economic Co-operation and Development (OECD), World Development Indicators Database, Food and Agriculture Organization of the United Nations (FAO Stat), United Nations Economic Commission for Latin America (CEPAL), and the Caribbean and International Energy Agency (IEA).

Table 12 presents the correlations analyzed between the chosen variables. The results confirm that there is no collinearity in the econometric model, as the values are below 0.99, showing that the model is correctly specified.

Table 12. Correlation analysis of biofuel production and food security variables in LAC countries

Control Variables	Biofuel production	Food Production Index	Prevalence of undernourishment	Per capita food production variability	GDP/ capita	Arable land	CO2 emissions	Food prices	Net Capital Stocks (Agriculture, Forestry and Fishing)	Growth population
Biofuel production	1.000									
Food Production Index	0.108	1.000								
Prevalence of undernourishment	-0.283	-0.223	1.000							
Per capita food production variability	-0.048	-0.387	0.247	1.000						
GDP/capita	0.250	0.242	-0.732	-0.288	1.000					
Arable land	-0.254	-0.095	-0.280	0.093	0.306	1.000				
CO2 emissions	-0.116	0.171	-0.614	-0.432	0.587	-0.077	1.000			
Food prices	-0.005	0.4116	-0.085	-0.132	0.08	-0.005	0.062	1.000		
Net Capital Stocks (Agriculture, Forestry and Fishing)	0.858	0.11	-0.339	-0.144	0.134	-0.319	0.126	0.74	1.000	
Growth population	-0.151	0.173	0.361	0.072	-0.36	-0.567	0.086	0.05	-0.03	1.000

Source: own construction

Table 13 shows the results of the panel data analysis of the dependent variable (biofuel production) and the remaining nine independent variables mentioned in Chart 3. Column (1) describes the variables, column (2) examines the relationship between the variables using pooled effects, column (3) uses panel data analysis with fixed effects, and column (4) uses random effects for the econometric model.

In the first estimation (pooled method), the production of biofuels has a significant negative relationship with the prevalence of undernourishment, the area of arable land, CO2 emissions, food prices, and population growth. On the other hand, the relationship is optimistic with the net capital stock and food production.

In the second analysis (fixed effects), the only significant effects are positive regarding food production and negative regarding population growth. Finally, the positive variables for random effects with significant levels are food production and net capital stock. The negative ones are undernourishment prevalence, GDP/capita, and population growth.

Cross-analyzing two of the three statistical estimates reveals a persistently negative relationship between the dependent variable and the two independent variables (population growth and undernourishment prevalence) at medium significance. In the opposite scenario, with a positive correlation, we have the food production index and net capital stock with medium and high significance.

Table 13. Panel data results of biofuel production and food security variables in LAC countries

Dependent Variable: Biofuel Production	**PE Estimation (1)**	**FE Estimation (2)**	**RE Estimation (3)**
Coefficient	1.3569e+04* (6.0723 e+03)		9.2957e+03 . (5.3044 e+03)
Food Production (Index)	8.6078e+01 . (4.6681 e+01)	5.7269e+01** (1.8125e+01)	6.0305e+01* (2.6633 e+01)
Prevalence of undernourishment (percentage)	-1.1433e+03*** (2.8303 e+02)	-2.2699e+02 (1.6809e+02)	-5.9938e+02** (2.1405 e+02)
Per capita food production variability (kcal/capita/day)	2.5569e+00 (1.5378 e+01)	7.7105e+00 (7.0465e+00)	7.3400e+00 (1.0105 e+01)
GDP/capita (USD)	-3.0761e-01 . (1.7372e-01)	-3.8696e-02 (9.0226e-02)	-2.9222e-01* (1.1890 e+01)
Arable land (percentage)	-9.0464e+01** (3.1513e+01)	-4.4206e+01 (1.4992e+02)	-9.4256e+01 . (5.6213 e+01)
CO2 emissions (TCO_2/capita)	-2.8339e+03*** (5.7334e+00)	1.44438e+03 (8.742e+02)	-8.9766e+02 (7.8418 e+02)
Food prices (Index)	-1.6312e+01* (7.2485e+00)	3.0638e+00 (3.6899e+00)	8.5159e-02 (4.537 e+00)
Net Capital Stocks (Agriculture, Forestry and Fishing) (USD)	2.9698e-01*** (1.89645e+02)	-1.8724e-02 (2.9470e-02)	1.6420e-01*** (2.9258e-02)
Growth population (Percentage)	-3.6431e+03* (1.4947e+03)	-2.2303e+02** (7.8245e+02)	-3.0249e+03** (9.8614e+02)
R-squares	**0.84154**	**0.22281**	**0.38544**
Adj. R -squares	**0.82858**	**0.10208**	**0.33516**
p-value	**<2.22e-16**	**0.0014982**	**2.4015E-11**

Note: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1, significant levels, respectively.

Source: own construction

In this study, the sample size (N) was 120 observations, with 10 variables in each analysis. Hausman 's test results in the next row reflect the model's statistical significance.

$$F = 19.517, df1 = 7, df2 = 103, p\text{-value} < 2.2e\text{-}16$$

In the case of the link between food security and the bioeconomy Kristinsson & Jörundsdóttir, (2019); von Braun (2018), indicate that the agricultural sector, which is the leading supplier of biomass for food security, must consider the linkages within the bioeconomy of agricultural productivity and commodity markets and land use collective action as trade-offs in interrelated value chains.

About the contributions of the bioeconomy to food systems, according to Gogoi et al. (2020); E. Trigo et al. (2023a) the transformation towards more sustainable and equitable food systems aims to provide healthy and nutritious food while creating livelihood opportunities and reducing negative impacts. In order to achieve these goals, the Summit on Food Systems United Nations (2021a) ,has identified five bioeconomy-related pathways for action. This study's findings determine the relationship between one of the region's bioeconomy sectors (biofuels) and three key food security variables in eight LAC countries, taking into account their intrinsic economic, social, and environmental impacts. This is consistent with all of the United Nations bioeconomy follow-up actions.

According to our statistical estimates, biofuel production in the LAC countries studied has a significant negative relationship with the prevalence of undernourishment, CO2 emissions, and population growth. On the other hand, there is a positive relationship between net capital stock, variability of food production per capita, and food production. Our findings align with studies of Gallagher, (2008); Ordoñez Olivo & Lakner (2023a); Subramaniam et al. (2020), which suggests biofuels can enhance food security while maintaining environmental quality. However, evaluating the need for government policies that support biofuels while simultaneously cutting emissions and contributing to the food supply is critical. This is especially true for Latin American and Caribbean countries, where establishing a strong biofuel sector can spur economic development by unleashing the region's potential and offering new opportunities for producers, particularly in rural regions (Janssen & Rutz, 2011b).

4.3.2.2. SDG 5: Gender policies and gender parity in scientific production in the bioeconomy in the LAC region.

Regarding the relationship between SDG 5 and gender equality, we conducted two different analyses: one reflecting the existence of gender policies in bioeconomy strategies in some LAC countries and the other on how gender parity affects scientific production.

In the first case, the same bioeconomy documents and strategies mentioned in the first chapter, available only for some LAC countries (9), were analyzed to determine whether they contain gender policies, objectives, principles, or goals. Figure 25 shows a summary of each country and its main bio-economy instrument (headings) and the gender focus of each instrument (sub-headings). Of the countries analyzed, a specific focus on gender inclusion in their bioeconomy instruments, reflected as a high-level priority, strategic focus, objectives, or plans and programs, is found in Brazil, Mexico, Paraguay, and Costa Rica. For the remaining countries, gender equality is a national focus in their bioeconomy framework.

For Mexico, Bolivia, and Paraguay, the gender approach in bioeconomy instruments concerns climate change and agriculture, two of the main axes of the bioeconomy principles.
It is important to emphasize that this analysis only considers the documents mentioned in the figure, which are those specifically related to the bioeconomy, which does not mean that the countries of Latin America and the Caribbean do not have policies or instruments approaching gender and equal opportunities in their national strategies in different economic and social aspects.

Figure 25. Gender focus in the bioeconomy frameworks of selected LAC countries
Source: own construction

As stated by (Ronzon & Sanjuán, 2020), the absence of visibility of gender concerns in international or national bioeconomy strategies leads to excluding the gender perspective from both scientific and policy agendas. Except for some policies that emphasize funding for diversity-oriented parties or actions related to education and training to increase the prominence of women in the bioeconomy (Smith & Diggans, 2020; Zabaniotou et al., 2019). The absence of a gender perspective in the bioeconomy emphasizes a masculine worldview and provides a less critical attitude to women's roles as subjects in transformation processes (Sanz-Hernández et al., 2022).

According to Charatsari (2023), incorporating gender into research or policy instruments is a difficult task because effective gender integration necessitates careful consideration of the overall context, given that gender is socially constructed and has complex relationships with economic, social, and other variables.

Our findings are consistent with BIO2REG (2024) , which suggests that to foster a fair and equitable bioeconomic transition, governance structures and policies must be more equalitarian and inclusive, considering social dimensions such as gender equality, inclusion, and community participation.

To reflect gender parity in scientific production in LAC countries, we conducted a linear regression and one-way ANOVA on three important variables.

For the dependent variable, we consider the female researchers as a percentage of total researchers in the countries (V1) as the gender parity variable and the percentage of GDP per capital invested in R&D (V2) and the percentage of GDP per capital invested in education (V3) in the countries as independent variables.

The analysis timeframe covered 2016-2021 for eleven Latin American and Caribbean countries, where data could be extracted for the three variables listed above. This data was collected using the UNESCO Institute for Statistics (UIS) and the World Bank Open Data.

- V1: Female researchers as a percentage of total researchers (HC)
- V2: Research and development expenditure (% of GDP)
- V3: Government expenditure on education, total (% of GDP)

Table 14 shows the coefficients results after applying the linear regression of the three variables; in both cases, the correlation is significant with p values less than 0.05. In the first case, the correlation between female researchers and GDP invested in R&D is positive and more assertive. In contrast, in the second case, the correlation between female researchers and the GDP invested in education is negative and weaker.

In terms of gender equity in scientific production, Huyer (2015) report that women's engagement in research remains elusive among researchers worldwide. According to UNESCO (2024) According to the report, almost one-third of all researchers worldwide are women. Women active in science make up 44.4% of the population in Latin America and the Caribbean, which is higher than in regions such as the European Union and the Arab States.

According to Brito (2020) Various factors influence gender disparity in Latin American and Caribbean countries. One is access to high-quality science education, another is advancement in scientific jobs, and the third is legislation and science access in general.
This is supported by Valenzuela-Toro Ana M. & Viglino Mariana, 2021) , who found that Latin American countries invest significantly less in science, technology, engineering, and mathematics (STEM) than high-income countries. Current results show a direct correlation between R&D investment and the percentage of female researchers.

Table 14. Coefficients on the linear regression applied to V1, V2, and V3 variables

	Unstandardized Coefficients		Standardized Coefficients	T	Sig	95.0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
(Constant)	48.844	4.075		11.985	<.001	40.700	56.987		
V2	28.813	9.106	.545	3.164	.002	10.616	47.009	.460	2.175
V3	-3.266	1.241	-.454	-2.633	.011	-5.745	-.787	.460	2.175

a. Dependent Variable: V1

Source: own construction

The above results are confirmed by the ANOVA analysis (Table 15) and Pearson's correlation coefficient (Table 16). Therefore, we can affirm that for the countries under study, investment in R&D has a direct impact on the percentage of women researchers. This suggests the need for governments and the various actors in society to invest much more resources in research and development, create opportunities for women in various science fields, and promote their active participation. According to data Huyer, (2015); UNESCO (2021) , women continue to be underrepresented in higher education and research around the world: from 53% of graduates, the figure falls to 43% for PhD graduates and 28% for female researchers. Despite an increase in female researchers, there is still a lack of gender equality policies in academic institutions (Cimpian et al., 2020; Conferencia Regional de Educacion Superior, 2018; Sinnes & Løken, 2014a).

Research publication patterns indicate a gender gap, with men publishing more articles than women (Hill & Rogers, 2012; Sinnes & Løken, 2014b; Tomassini, 2021). According to the Elsevier Gender Report 2024, which examines women's participation in research globally across 26 subject areas, women's participation in research has typically increased over the past two decades. However, inequities continue, especially in STEM fields. Female scholars produce fewer publications than men on average across all countries, regardless of authorship (Bayazit, 2024).
Studies specifically addressing gender differences in the fields of bioeconomy research (Olivo et al., 2024), suggest that women are underrepresented in rural development and bioeconomy sciences, as the number of male authors in the analyzed dataset was nearly three times that of female authors. The study also observes that women's contributions are regarded as less important than those of male scientists. This reduces the overall number of citations and maintains female researchers' invisibility.

Table 15. ANOVA test

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	543.906	2	271.953	5.109	.009[b]
	Residual	3353.831	63	53.235		
	Total	3897.738	65			

a. Dependent Variable: V1

b. Predictors: (Constant), V3, V2

Source: own construction

Table 16. Correlation's analysis

		V1	V2	V3
Pearson Correlation	V1	1.000	.212	-.053
	V2	.212	1.000	.735
	V3	-.053	.735	1.000
Sig. (1-tailed)	V1	.	.044	.337
	V2	.044	.	.000
	V3	.337	.000	.
N	V1	66	66	66
	V2	66	66	66
	V3	66	66	66

Source: own construction

Although the correlation between V1 and V3 is negative, it may reflect the scarcity of women who, even with degrees in different subjects, are not involved in scientific research. This may indicate that women still face obstacles in occupying key academic positions in universities and participating in relevant research.

Finally, in Figure 26, we graphically present these relations with a logarithmic regression better adapted to the regression coefficients to provide an overview of the different correlations between the variables. In the figure below, besides confirming the previous statements, we can note the positive and high correlation between V2 and V3. Since universities and research institutes are most closely related to central government investment, there is a direct logic between a country's investment in education and its investment in science and research as a percentage of GDP.

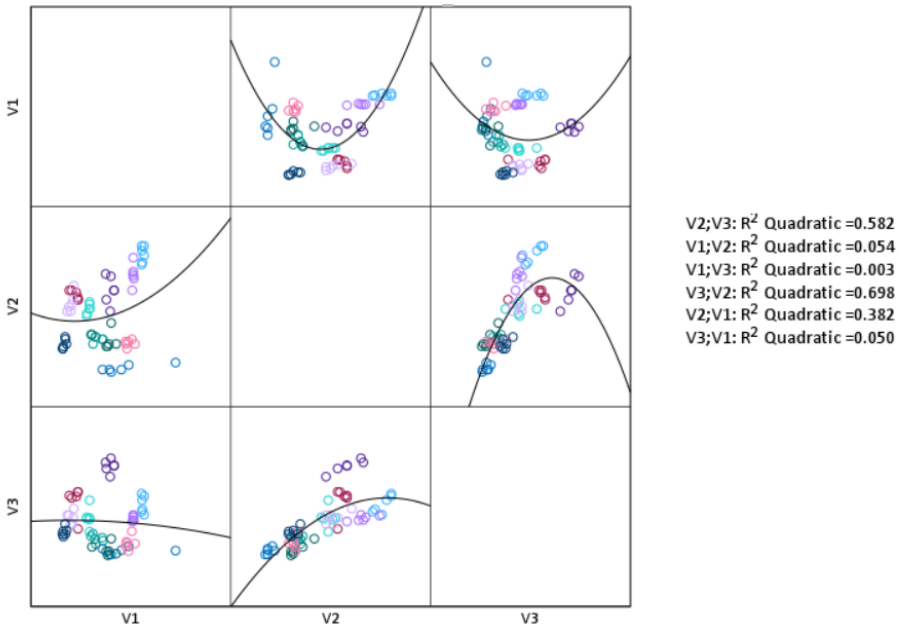

Figure 26. Correlation between the dependent and independent variables under study.
Source: SPSS analyst based on the correlation variables studied

4.3.2.3. SGD 9,11,13: Life Sustainable Cycle Assessment of the use of bamboo as a bioeconomy innovative model.

To provide a comprehensive analysis of the sustainability contribution of a specific sector of the bioeconomy, which would also serve as an example of a methodology for other sectors, we decided to conduct a case study on a specific value chain within a Latin American country (Ecuador), the production of bamboo, which is an important source of income for farmers and an alternative construction material for the South American nation.

After considering various methods, we decided to use the Sustainable Life Cycle Assessment (SLCA), which considers the impacts of the three principal axes of sustainability: environmental, economic, and social.

According to Lago-Olveira et al. (2024); Lewandowski (2017; Patel et al. (2022); Robert et al. (2020) SLCA, as a methodology, considers all stages of the value chain and makes it possible to identify trade-offs between alternatives and the most sustainable and appropriate strategies for developing bioeconomy activities. For the European Commission (2023a) life cycle assessment (LCA), based on ISO 14040/44, is a powerful and vital sustainability tool.

Area under study

Ecuador has rich bamboo resources regarding species diversity, distribution, and abundance in Latin America. Ecuador hosts a total bamboo growing area of 600,026 hectares, equal to 2 % of the country's total geographical area. Considering all the productivity and services of the bamboo activity, the bamboo sub-sector accounted for at least 0.5% of the Ecuadorian GDP in 2017.

Bamboo-related activities directly influence 12 % of the employment generated in the agricultural sector (26 % of the Ecuadorian population and 65 % of the population in rural areas), providing temporary employment and additional sources of income to 503 000 people who depend on bamboo for their livelihoods in the provinces of Manabí, Los Ríos, Guayas, Santo Domingo de los Tsachilas, Napo, and Esmeraldas.

The two provinces chosen for the study have the most excellent bamboo extension in the country. The primary and secondary data for the analysis were collected in these two provinces.

This part of the research was carried out in conjunction with INBAR (International Bamboo and Ratan Organization), which provided the baseline data, technical assistance, contact with key actors to be interviewed, and logistical support within the territory for the primary data collection.

Scope, functional unit, and system boundary

The SLCA study covers bamboo production, harvesting, preservation, and processing in two of Ecuador's largest bamboo-producing provinces.

The system described, therefore, follows the 'cradle to gate' principle. This means that the bamboo field is assessed from the production stage, from year 1 to year 4, up to its basic processing as a building material, either as a whole stalk or as a preserved stalk (Figure 27).

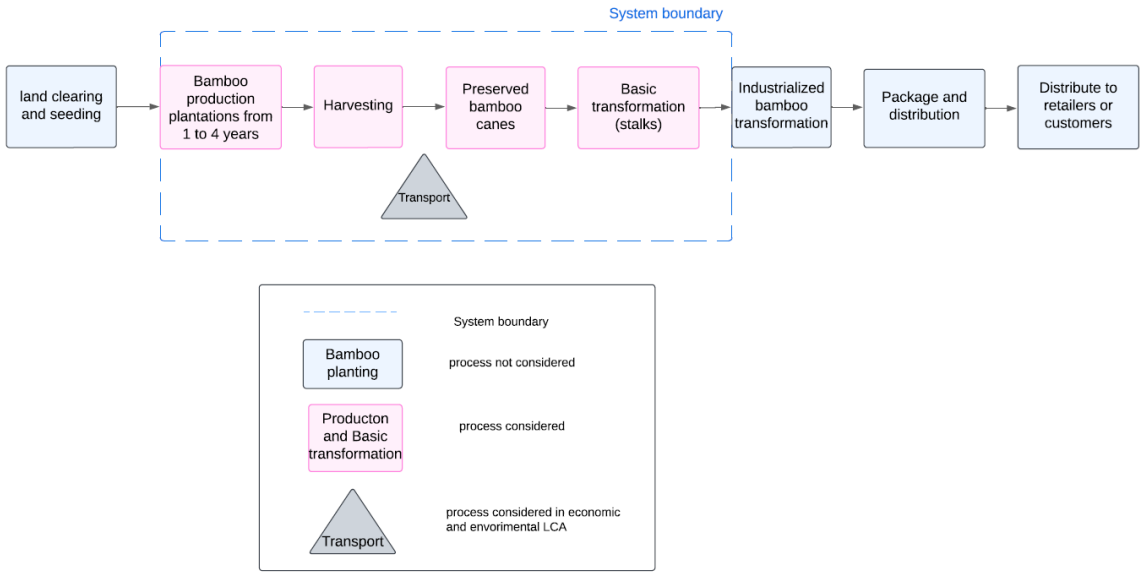

Figure 27. The product life cycle of bamboo production and preservation is considered a system with system boundaries
Source: own construction

Environmental, economic, and social considerations of the analysis

The study focuses on the environmental and economic impact assessment of 1 kg of canned bamboo, which considers the calculation of the environmental impact and not the individual processes. The OPENLCA program with the corresponding license was used to carry out the environmental and economic LCA.
The ecoinvent database, which has a specific procedure for non-timber forest products such as bamboo canes, was used for the environmental analysis. For the impact analysis, the CML methodology was used with the following impact categories:

1. abiotic depletion,
2. acidification,
3. eutrophication,
4. global warming,
5. ozone layer depletion,
6. human toxicity,
7. freshwater aquatic ecotoxicity,
8. terrestrial ecotoxicity, and
9. photochemical oxidation

The inventory is segmented according to system boundaries, which apply to all sustainability dimensions under analysis (Table 17). Bamboo production and conservation are considered for the two Ecuadorian regions analyzed in this study. Primary data collected for each group identified in the value chain is also considered for the social impact assessment.

Table 17. Input-output table of bamboo production and preservation in Ecuador (per 1 kg of bamboo)

Inputs	Quantity	Outputs*	Quantity
Production 1 until 4 years		Bamboo preserved	1kg
Manual work (converted in EPWH/hour)	0.08525MJ	"Strips" bamboo manual	1kg
Fertilizers (N, P, K)	0.032KG	"Strips" bamboo mechanic	1kg
Transport	0.00455kg/km		
Harvesting			
Manual work (converted in EPWH/hora)	0.032MJ		
Animal work (converted in KW/hour)	0.00100		
Preservation			
Manual work (converted in EPWH/hora)	0.087		
Borax	0.073 kg		
Boric acid	0.073 kg		
Transport	0.003 kg/km		
Electricity	0.010kHw		
Tap water	0.0010t		
"Strips" processing			
Manual work (converted in EPWH/hora)	0.0696MJ		
Lubricant oil	00015kg		
Diesel burned in agriculture machine	0.810kWh		
Electricity medium voltage	0.8188kWh		

*Waste is not considered an output in this calculation since it is recycled and used for different purposes throughout the process.

Based on the UNEP/SETAC guidelines for evaluating the social impact of the bamboo product cycle, we designed participatory surveys according to the types of actors consulted in the two regions of Ecuador (Table 18).

Table 18. Consulted actors in the two regions of Ecuador for the SLC impact

Involved and/or affected stakeholders	**Consulted actors (affected and/or involved stakeholders + external concerned stakeholders)**				
	Farmers and Farmers Union	**Workers**	**Value Chain Actors**	**Public Actors**	**Academic Actors**
Farmers	X			X	X
Workers	X	X		X	X
Value Chain Actors (preservation centers, transporters, traders, and retailers)			X	X	X
Local community	X		X	X	X
Society				X	X
	Survey 1	Survey 2	Surveys 3 to 6	Survey 7	Survey 8

Source: own construction

For the stakeholders in the considered processes, the following groups with subcategories were identified:

Farmers: In this category, we consider the bamboo producers in the two regions, considering the following subcategories: livelihood and well-being, inclusiveness, productivity, farmers' holders, and trading relationships.

Workers: In this category, we include workers employed on a temporary or permanent basis in bamboo farms and bamboo collection and processing centers. We consider the following subcategories for this actor: child labor, fair salary, working hours, forced labor, health and safety, social benefits, Equal opportunities/discrimination, and the employment relationship.

Value chain actors: This category includes bamboo collection and preservation centers, bamboo transporters, and traders. The following subcategories are considered: fair competition, wealth distribution, and supplier relationships.

Local community: Manabí and Napo provinces were considered for this scope of actors. We contemplate the following subcategories for these actors: access to public and community infrastructure, safe and healthy living conditions, respect for Indigenous rights, community engagement, and local employment.

Society: the society of both regions under analysis. Considered subcategories: contribution to economic development, corruption, technology development, and prevention of armed conflicts.

The indicators to be evaluated in each subcategory and their weighting will be explained later in the tables corresponding to the analysis of the two provinces' social impacts. Regarding life cycle costing, to present understandable information, we add cost information to each flow/process through the whole product system previously described and sum it under the fixed and variable cost categories.

Environmental Impact Results

The impact results are separated into three major groups of studies based on the outputs evaluated as the final product derived from bamboo production and basic processing. It is crucial to note that in the preservation of bamboo pole, the production system is considered, in which the plantation is treated with chemical fertilizer and then passes through a preservation process to retain the physical qualities for subsequent use as a construction material. Using the same reasoning, the stalks "stripss" are divided into manual and mechanical processes, including using machines and fuels to process the conserved bamboo.

According to the CML approach impact analysis, the values in all categories are less than zero, except for climate change, energy resources, and human toxicity (Table 19). The values for the remaining three impact categories are cero, meaning no influence exists.

Table 19. Environmental LCA results for bamboo in two regions of Ecuador

Impact category	Reference unit	Preserve pole (1 kg)	Strips manual process (1kg)	Strips mechanic process (1kg)
Acidification	kg SO2-Eq	0.00169	0.0017	0.00192
Climate change	kg CO2-Eq	0.49283	0.34825	0.53817
Ecotoxicity: freshwater	kg 1,4-DCB-Eq	0.15941	0.01758	0.21403
Ecotoxicity: terrestrial	kg 1,4-DCB-Eq	0.01296	0.00403	0.01601
Energy resources: non-renewable	MJ	7.27	5.66	7.893
Eutrophication	kg PO4-Eq	0.00121	0.00060	0.0016
Human toxicity	kg 1,4-DCB-Eq	2.04834	0.6745	2.554
Material resources: metals/minerals	kg Sb-Eq	0.00018	0.00018	0.00018
Ozone depletion	kg CFC-11-Eq	1.04E-8	9.29E-9	1.13E-8
Photochemical oxidant formation	kg ethylene-Eq	0.00010	7.67E-5	0.00012

Source: own construction

We can see a significant difference between the manual and mechanical processes of the "stripss" in the sense that all of the impact categories are substantially lower in the manual process. The key argument is that in the case of manual processing, the only input considered is the human labor utilized to process the preserved bamboo without any additional machinery or fuel. The climate change category analyzed atmospheric emissions converted to CO_2-equivalents. Figure 28 compares timber and non-timber subproducts based on reference studies to provide an overview of the results obtained with conserved bamboo. Notably, emissions might differ depending on factors such as processing methods, treatment, and energy sources used.

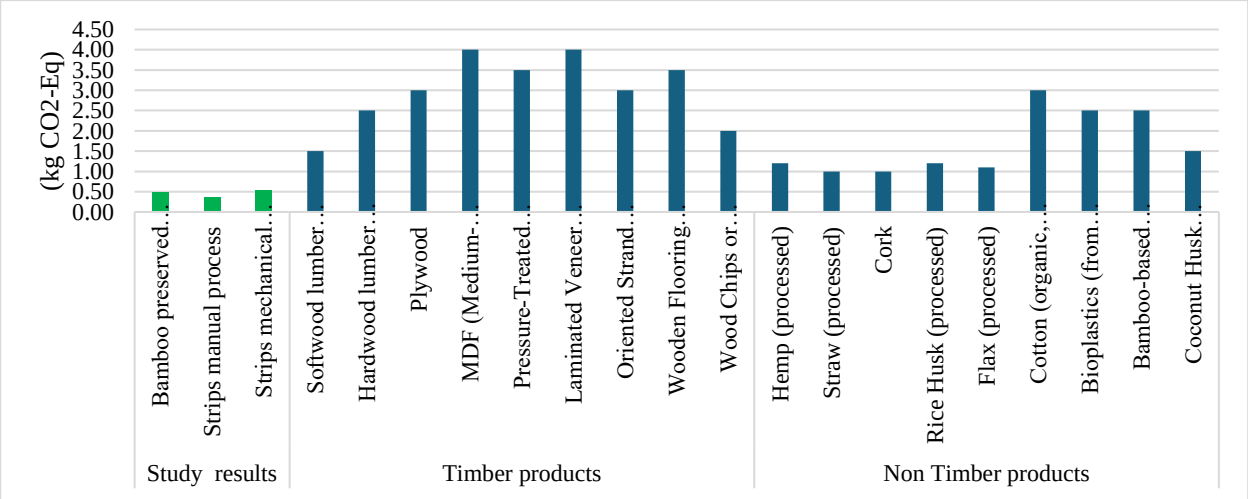

Figure 28. Comparison of Carbon Emissions of study results and Timber and Non-Timber Products
Source: for timber products (Bergman et al., 2014; Costa et al., 2024; Hawkins, 2021; Koning et al., 2005; Puettmann & Wilson, 2005; Sandin et al., 2016; Sathre & O'Connor, 2010). For non-timber products (Fitzgerald et al., 2021; Islam et al., 2024; J. Li et al., 2016; Zampori et al., 2013)

According to our findings and a comparison of data gathered from other timber and non-timber goods studies, emissions from bamboo preserved as a pole and "strips" are lower than emissions from timber

products, even untreated. The same applies to non-timber products, where our results are below the values of all the materials.

Figure 29 shows the main impact contributors regarding kg CO2-Eq emissions of the outputs under study. In the case of preserved poles, the main emission contributors are the chemicals used to preserve the poles, followed by the inorganic fertilizers used in bamboo production. The main contributor for the manual "strips" is the chemicals used in bamboo preservation and partially the transportation. For the mechanic "strips", since the process involves using specific machinery and fuels, the main contributors are those related to this process and the previous steps in preserving bamboo.

Climate change impacts are calculated based on the inputs provided for each flow in the bamboo process. They are directly related to the use of fossil fuels in each step of bamboo production and processing.

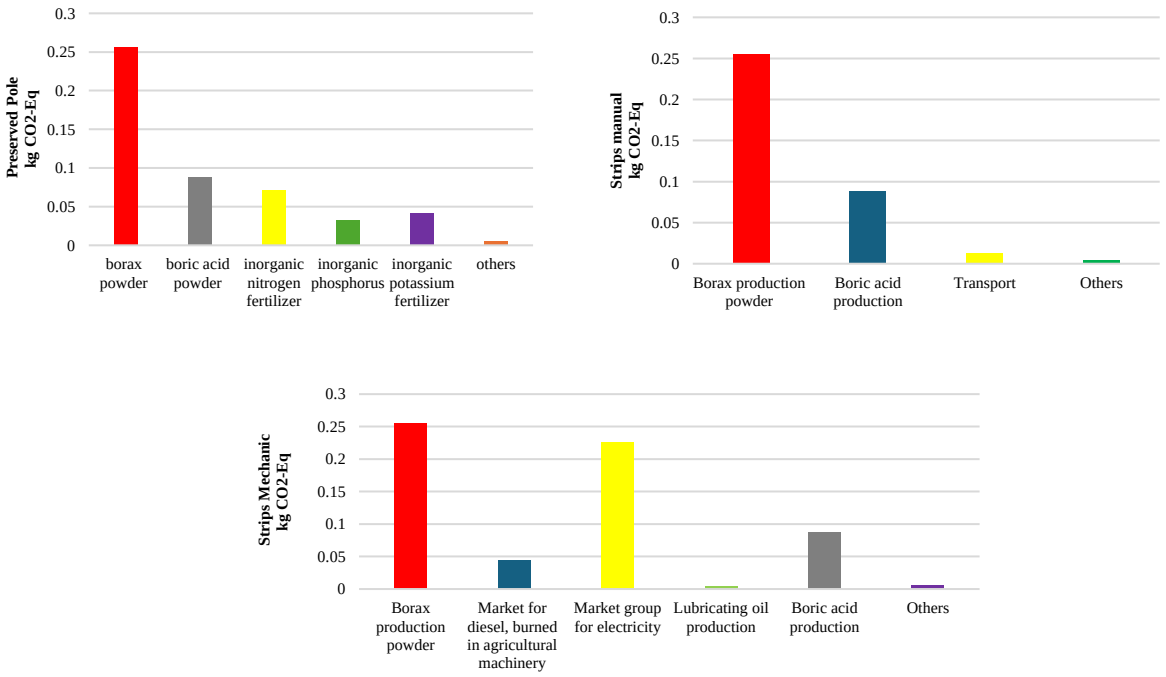

Figure 29. Main impact contributors of Kg CO2-Eq emissions of the studied outputs
Source: own construction

In the case of human toxicity, this parameter is measured in kilograms of 1,4-dichlorobenzene equivalent (kg 1,4-DCB-Eq) and mainly quantifies the potential human health impact of chemicals emitted during a product's lifecycle. For our study, the proportion of chemicals is mainly during bamboo's preservation and mechanical processing. The highest value corresponds to mechanical “strips”, followed by preserved pole, and in the last position the manual strips. Compared to other wood subproducts such as medium-density Fiberboard (MDF), recycled engineered wood, or standard plywood, the parameters of the present study still keep the average of the mentioned timber products. However, it is important to note that the values in this study are higher than other non-timber products, such as natural fibers, but much lower than products derived directly from fossil resources.

Finally, the values obtained in the study are at the same average level as non-wood products such as bio-based plastics and natural fibers in terms of energy resources (non-renewable) measured in MJ and well below those for processed wood products such as plywood, laminated wood, or blockboard.

For Van Der Lugt & King (2019), bamboo could be a critical component in the transition to the bioeconomy by providing a viable, bio-based alternative for non-renewable, carbon-intensive 'techno-cycle' materials. According to Lorenzo et al. (2020) in general, the use of bamboo poles in the construction industry has an environmental advantage because of the reduction in carbon dioxide generation compared to conventional structural materials, as well as the comparative advantage of maturing at a faster rate than typical timber products (Tan Phuong, 2020; Yadav & Mathur, 2021). According to International Network for Bamboo and Rattan INBAR (2015) industrial bamboo materials have a larger annual yield than hardwoods, higher processing efficiency, and are competitive depending on the production scenario.

The study of Marcel Gauch Paul Vanegas Dolores Sucozhañay et al. (2023) evaluates various types of wood and non-wood construction materials, including bamboo, using a life cycle analysis. This study concludes that, generally, when materials are processed artisanal, the environmental impact is minimal since it requires a substantial quantity of work, which is the primary energy source for processing. On the other hand, mechanized production increases environmental emissions due to using equipment as a processing energy source.

Other findings from the study of Yadav & Mathur (2021); Zea Escamilla et al. (2018) , who conducted a comparative life cycle assessment to measure the environmental impact of various construction materials such as bamboo, brick, hollow concrete block, and engineered bamboo in construction, revealed that the engineered bamboo construction system has the lowest environmental impact. This means that bamboo-based constructions not only help to reduce atmospheric CO2 levels but also create new and long-term carbon sinks (Gan et al., 2022).

Economic Impact Results

Regarding the economic impact of the results, Figure 30 summarizes the economic aspects of bamboo production and preservation. The most expensive phase in bamboo manufacturing is preservation and conservation, followed by establishment and maintenance. Human labor is the major contributor to the production cost of bamboo maintenance, followed by inputs. In the case of preservation, the inputs used to preserve the bamboo account for the most significant proportion, followed by human effort and tools.

Generally, bamboo production and conservation in Ecuador are primarily carried out using manual labor rather than mechanical methods. Our findings show that labor contributes significantly to production costs. Regarding income for the two main actors in the assessed chain, the ratio between farmers and bamboo processors is 1 to 4, considering data on market prices after covering production costs in the unit of analysis, which in this case is 500 poles/ha. These numbers also represent the realities of the bamboo production chain, in which producers earn less profit than those who add value to the product. In rare circumstances where producers have their conservation center as an organization, the income remains with the farmers.

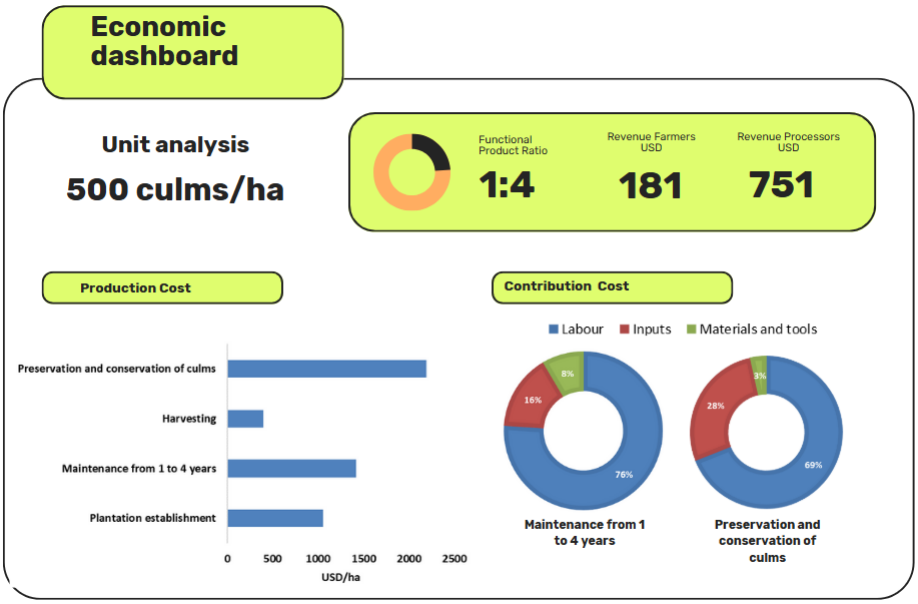

Figure 30. Economic dashboard of the production and preservation of bamboo poles
Source: own construction

Regarding the comparison with the production cost of other type of timber products used as well in construction, the study of Cubbage et al. (2022) present the production costs per hectare across various regions and management intensities for timber products; in the case of Latin American countries, the cost of establishment per hectare varies between 1750$ USD and 5000$ depending on the type of wood, years of cultivation, and production systems. The costs mentioned do not include wood processing. If we compare the cost determined in our study for bamboo in Ecuador, we are within the ranges established with the advantage that bamboo is a faster-growing plant than any other timber product.

In addition to the foregoing, for the current study, we added an analysis of the production costs of each process studied in the same unit analysis but divided by kilograms to the production system. Figure 31 depicts the OPEN LCA software's calculations in percentages of the production cost contribution for each step. According to the same rationale, the results suggest that the inputs utilized for pole preservation are the top contributors, followed by harvesting and bamboo production, which rely heavily on human labor for most agricultural activities. The economic features of the bamboo "strips" were not considered in these calculations because the inputs utilized for the process do not provide economically significant value to the analysis.

Contribution	Process	Required amount	Total result [EUR]	Direct contribution [EUR]
100.00%	Preserved culm of bamboo chemical	1.00000 kg	1.10791	0.51892
32.17%	boric acid production, anhydrous, powder | bo...	0.29300 kg	0.35640	0.35640
13.49%	borax production, anhydrous, powder | borax, ...	0.29300 kg	0.14943	0.14943
07.38%	Harvesting bamboo in Manabi	1.00000 kg	0.08178	0.07149
00.09%	electricity production, compressed air energy ...	0.03600 MJ	0.00098	0.00098
00.04%	tap water production, conventional treatment ...	1.00000 kg	0.00040	0.00040
00.00%	transport, freight, lorry 16-32 metric ton, EURO...	3.00000E-6 t*km	8.78232E-8	8.78232E-8

Figure 31. Percentage of the cost contribution in the preserved bamboo by kg
Source: own construction

Regarding the economic evaluation of bamboo production and processing, the same study of Marcel Gauch Paul Vanegas Dolores Sucozhañay et al. (2023) indicates that the economic profit of bamboo increases with the preservation process. Furthermore, introducing more mechanical processes increases social performance; materials with semi-mechanized production are in higher demand, making them more economically profitable.

Social Impact Results

After determining the stakeholders for whom the S-LAC will be performed, we identify the subcategories and indicators for each subcategory to be reviewed by the UNEP/SETAC recommendations.

One key step in the Social Impact Results Analysis is establishing an evaluation scale on which the social impact for each indicator on the impact analysis subcategory can be weighted. Table 20 displays the scales and ponderation for each category in the analysis.

Table 20. Scale Evaluation of the Social Impact Assessment of Bamboo in Ecuador

Scales of evaluation for S-LCA		
Very poor	VP	0
Poor	P	1
Medium poor	MP	2
Fair	F	3
Medium good	MG	4
Good	G	5
Very good	VG	6

Source: own construction

After analysing the interviews with the various stakeholders, we could weigh each indication and compare them to the optimal levels. These optimal values were acquired from several institutional, governmental, and regional data sources in Ecuador, establishing the fundamental parameters for the numerical indicator.

Table 21 summarizes the Analysis of Social Impact Results in Ecuador's two regions. The living conditions of the farmers, the leading actors involved in the production of bamboo, are not optimal, which is the reality of the rural areas of Ecuador, where most of the producers do not have full access to household services or their income is not sufficient to meet their food security needs. Regarding productivity metrics, average bamboo production is less than optimal; this may be explained by the fact that present farmers' bamboo plantations are sourced from natural areas that require maintenance agricultural work to become more productive over time. One notable characteristic of Ecuadorian farmers in general, which is also reflected in this study, is that the average age of a farmer is more than 50 years old, and the degree of education in most cases is less than middle school.

Most of the parameters evaluated are above the mean in the worker's category, except for the employment relationship. This is because, in most cases, the workers are hired according to the agricultural needs of the plantation, and no formal employment instrument is signed. Few interviews were performed in this category, as most farmers are small producers who rely on family members to manage their bamboo plantations.

For the value chain stakeholders, we summarized all the actors in this category to get an overview of the evaluated subcategories. In general, the actors in this category believe that there is little competition; however, the existing competition is not regulated in any way, resulting in price uncertainty and, in general, substantial environmental impacts when unethical intermediaries harvest the entire bamboo area in farms without any technical consideration. When bamboo produce is sold in the local market, the parties do not have a legal agreement. However, they consider that the prices received by the actors in this category are fair enough to have revenues during the year.

Regarding the subcategories and indicators reviewed for local communities, we did a general analysis using institutional and governmental records that reveal the reality of the study's regions. According to national data, the average population in the two provinces has access to drinking water (69%), electricity (94%), sewage system (46%), and garbage collection (83.4%), albeit these figures may be lower in remote regions. In 2023, Manabí and Napo had an unemployment rate of 2.15%, 68% informal employment, and 64.8% multidimensional poverty. All the numbers mentioned describe the living conditions in this location. Hence, we evaluate the indicators in our matrix as Medium Poor.

Finally, in evaluating the social subcategory, the two categories related to bamboo's contribution to the economy and institutional development, we discovered support for bamboo as an alternative source of income for farmers, a potential material for the construction industry, and a source for the conservation of local ecosystems in various documents and among interviewees. The country generally confronts issues in terms of security and corruption indices; hence, their weighting in the current analysis is low.

Figure 32 shows a radial diagram of each stakeholder's evaluation of social impacts to visually represent the information indicated in the social impacts table. The same concepts previously mentioned can be seen, and the social impacts have an average weighting of 2.9 points.

Table 21. Analysis of Social Impact Results in Ecuador's two regions

Actor	Subcategory	Indicator	Optimal values	Social Impacts
Farmers	Livelihood and well-being	Access to domestic services	the family has permanent access to potable water, light, internet, and mobile signal	P
		livelihood sufficiency (food and income)	The income of the family covers the basic food basket or minimum wage	MP
	Inclusiveness	Participation in farmers' organization	the farmers have the legal frame and conditions to form an association	VG
		Ownership of the land	farmers are owners of the land on which they produce	G
	Productivity	Optimal planting yield	800 bamboo poles/ha	MG
		contract skill labor	farmers hire day laborers to manage their crops	MG
		Access to crop services (fertilizer, credits, seeds, etc.)	Farmers have sufficient means to access the services required to manage their plantations.	MP
	Farmer's holders	Age of farmers	From 18 to 60 years (international parameters)	G
		level of education of the farmers	middle and higher education	P
	Trading relationships	relationship with buyers	It has a fair and mutually beneficial relationship.	F
Workers	Child labour	Presence of child labor	No presence of child labor	MG
	Fair salary	Payment per journey day work	22 dollars per day worked (based on the monthly minimum wage in Ecuador)	F
	Working hours	Adequate working hours (average)	8 hours	F
	Forced labour	Evidence of forced labor in the production processes	No forced labor	MG
	Equal opportunities/discrimination	The existence of racial or gender discrimination	No discrimination or gender disparities	F
	Health and Safety	Exposure to agrochemicals or other working risk conditions	No working risk exposure	F
	Social benefits/social security	The employer provides affiliation to the National Social Security	the worker is affiliated with the social security system	MP
	Employment relationship	Employment relation	Formal contract	MP
Value Chain Actors (preservation centers, transporters, traders, and retailers)	Fair competition	Fair competition	There is competition regulated	MP
	Wealth distribution	Contractual instruments within the supply /value chain	Between the value chain actors exist contractual instrument	P
		Price that covers all the production costs and returns an acceptable profit margin	The price at which bamboo is marketed is profitable for all stakeholders	F
	Supplier relationships	Intermediation between the actors	There is no intermediation between the chain actors	MP
Local Communities	Access to public and community infrastructure	Access to public and community infrastructure	The communities have access to the public and community facilities	MP
	Safe and healthy living conditions	local and regional basic service coverage (water, electricity and sewerage)	100% coverage of the basic service for the communities	MP
	Respect for Indigenous rights	Rights conflicts	Respect for the Indigenous rights	F
	Community engagement	Actions to Promote Community Engagement	The communities have the legal frameworks and conditions to exercise their association and associative work rights.	VG
	Local employment	Unemployment Statistics for Province	Lower unemployment rate	MP
Society (Country level)	Contribution to economic development	Contribution of the bamboo sector to economic progress	Contribution of the bamboo sector to economic progress (country level)	F
	Prevention and mitigation of armed conflicts	Presence of violence in the territories	No presence of violence in the territories	MP
	Technology development	Local, national, and international institutions promote the development of productive chains such as bamboo.	Local, national, and international institutions promote the development of productive chains such as bamboo.	MG
	Corruption	Risk of corruption in the region/country	Low risk	P

Source: own construction

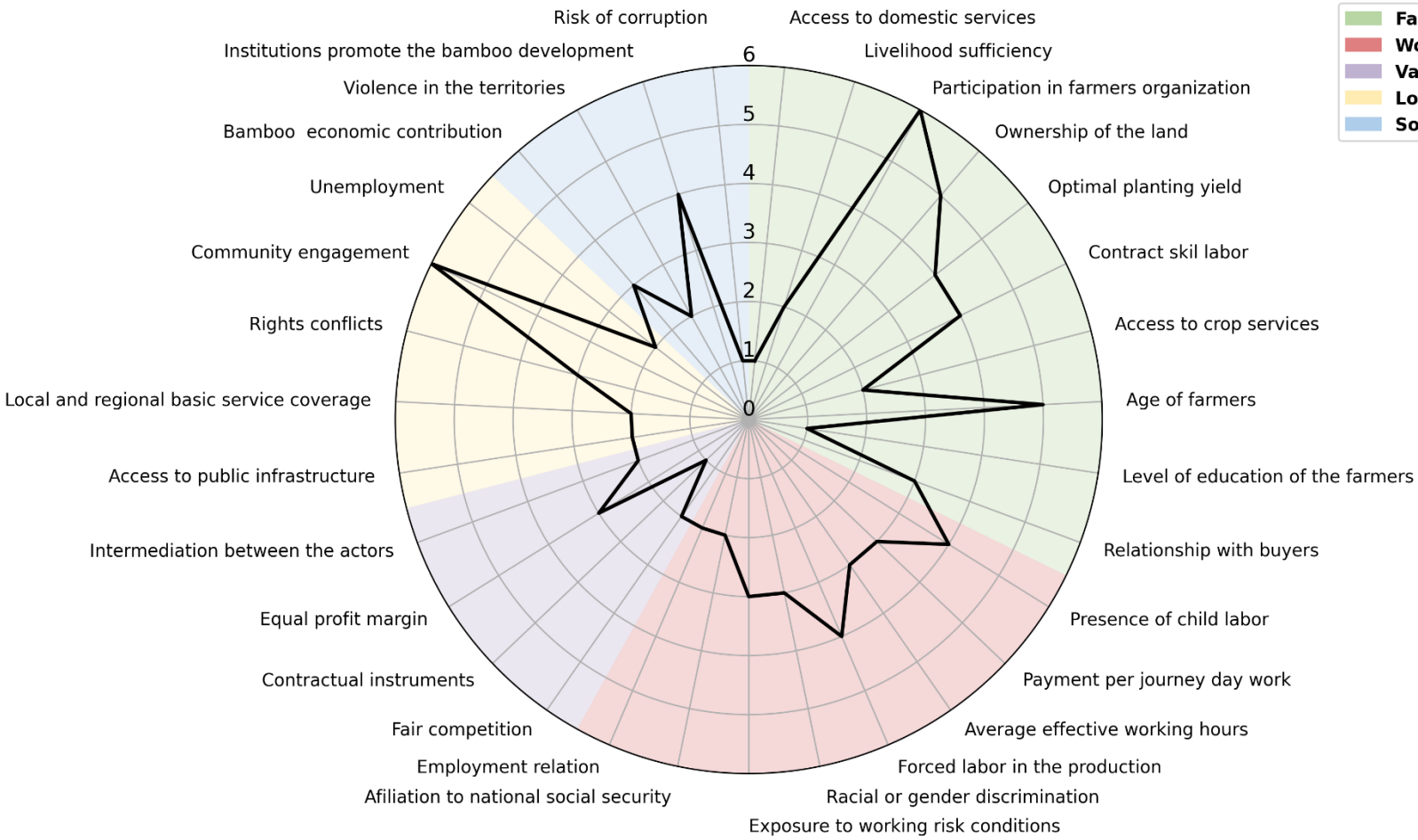

Figure 32. Visual representation of the Social Impact Analysis of Bamboo subproducts
Source: own construction

Regarding the social impact on the bamboo production chain, Zea Escamilla et al. (2018) results show that for Ghanaian bamboo bicycle companies, their performance did not have a negative socioeconomic impact in most subcategories evaluated in the bamboo production communities, and even made bamboo resource owners aware of the value of bamboo, allowing them to negotiate a reasonable price to contribute to their development.

The study of Marcel Gauch Paul Vanegas Dolores Sucozhañay et al., 2023), evaluate the social performance of the artisanal production of Adobe, Panelon Brick, and bamboo in various regions of Ecuador; as a result, it was observed that the social impacts in the artisanal production of Adobe and Brick are primarily negative, while in Guadua cane they tend to be more positive. The results given for bamboo differ significantly between the processes needed to produce a bamboo pole compared to a block of adobe or panel brick. The difference lies mainly in the human labor required to produce each material. In the case of the guadua reed, the raw material extraction and preservation process does not involve a significant transformation, which is not the case with the other two materials.

Summarizing the results, the study shows the importance of the bioeconomy sectors in the region using a holistic approach. Starting with identifying these sectors through different types of analysis, moving on to macroeconomic quantification of the percentage of GDP represented by the bioeconomy sectors. It ends by analyzing the relationship between certain GVA and variables related to the sustainable aspects of the bioeconomy. The case study of bamboo in Ecuador demonstrates the possibility of measuring the different aspects of sustainability in a bioeconomy value chain in a way that shows the sustainability of a particular product with social, economic and environmental impact indicators.

The results described above do not allow us to generalize the bioeconomic reality of the countries. This is because the information available for the different analyses is neither standardized nor updated. However, an attempt has been made to include as much data as possible from each country. This has been done in order to reflect general data on the situation of the bioeconomy in LAC.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Several principles characterize the bioeconomy as an alternative economic model that prioritizes the use of biomass to produce products and services that take a holistic approach to sustainability. The current study encompasses recent worldwide definitions and evaluations of the potentialities of the Latin American and Caribbean regions. The bioeconomy sectors of the LAC region were determined based on several analyses, first the compilation of the concept bases of the bioeconomy, the study of the regional and countries' institutional bioeconomy strategies, the bibliometric analysis of scientific articles related to bioeconomy sectors in the region, the opinion of essential stakeholders of the LAC region, and finally the immense potential of the region to produce biomass.

The bioeconomy sectors in Latin and Caribbean countries were divided into four categories: primary industry, primary value-added sector, high value-added, and bioeconomy services. All sectors have a transactional axis for sustainability, which could assist countries in allocating natural resources in a socioeconomic and environmental alternative paradigm. After evaluating various studies and methodologies and taking into account the limitations of the countries' economic information, we agree that the Supply and Demand tables, which are part of the countries' National Account Systems, are the most up-to-date and uniform data set that we could use to determine the economic importance of the bioeconomy sectors in the region. The information was obtained from CEPAL, the Economic Commission for Latin America and the Caribbean. We could only study 11 of the 33 countries in the most recent period in which it was possible to synchronize information across all countries, which was in 2018.

The authors' criteria for classifying each economic product and activity in the supply and demand tables were based on preliminary results from the classification of the various bioeconomy sectors in the LAC region. In general, among the bioeconomy sectors studied, the primary value-added sector has the largest share in terms of supply and demand. The bioeconomy services follow, with the primary sector coming in last. Central American countries such as Nicaragua and Honduras have the most significant percentage of primary value-added production on the supply and demand sides, followed by Brazil, Argentina, Mexico, Colombia, and Ecuador. Costa Rica, Ecuador, Colombia, Mexico, and Brazil are leading contributors to the bioeconomy service industry. Because of their natural attractions, biodiversity, and cultural qualities, the countries above are well-known in the region as reasonably competitive in the global tourism ranking. Nicaragua, Honduras, and Ecuador have the highest primary sector representation on the supply side. Nicaragua is once again among the top countries regarding demand, after only Brazil and El Salvador.

Nicaragua, Honduras, and Costa Rica have the highest share of imports in all bioeconomy sectors. Mexico, Ecuador, and Argentina have the lowest share of bioeconomy imports in each industry. Regarding the export percentage of bioeconomy sectors, Honduras, El Salvador, and Argentina have the highest shares. Mexico, Colombia, and Peru are at the bottom of the list.
To quantify a crucial macroeconomic indicator of the contribution of bioeconomy sectors, we use the supply-demand tables of the nations investigated to determine gross value added. The trends from prior reports maintained, with Central American countries such as Nicaragua and Honduras having the highest primary sector values in 2018, while Mexico and Chile had the lowest. The trajectory of

primary value-added remained constant with the previous analysis, with adjustments for the weakest contributors, Brazil and Colombia.

One of the most notable outcomes of this study was the inability to identify sectors associated with high-value-added bioeconomy in the analyzed countries' national accounts. According to stakeholders interviewed and institutional papers studied, some sectors, such as biocosmetics in Argentina and Costa Rica and bioplastics in Colombia, Brazil, and Honduras, might be classified as high-value-added. However, this bioeconomy product is not explicitly classified in the national accounts to be measured using the abovementioned approach.

Regarding each subsector's contribution to the bioeconomy in the examined LAC nations, agriculture is the main contributor for the primary sector, with Nicaragua and Honduras as the leading countries. At the same time, Brazil and Chile have the lowest shares. In the case of the Central American countries, agriculture is the primary source of production and exports; however, the sector urgently needs diversification into manufacturing or high-value product processing. While Brazil and Chile have large primary industries, they do not contribute much to their countries' economic balances; these countries' trade balances are mainly concentrated on non-bioeconomic sectors such as mining and oil.

The major sub-sector contributor for the primary value-added sector is 'Food, textiles and leather,' with the three Central American countries and Ecuador as the main contributors. Argentina, Chile, Nicaragua, Honduras, and Brazil are the top contributors to the subsector manufacturing industries, including cellulose, wood products, tobacco, etc. Finally, in the case of biofuels, only Brazil and Colombia include the various biofuel-related products and activities in the data analyzed, with Brazil leading the way in the area.

Given the importance of sustainability in the bioeconomy sectors, we conducted four separate analyses to investigate the relationship between the SDGs as a primary sustainability criterion and the bioeconomy sectors in Latin American and Caribbean countries. Based on the keywords established in the bibliometric analysis performed in the first section of the results, we conclude that the articles evaluated in the corpus have a numerical relationship to the majority of the SDGs, except SDG 17. The SDG with the most linked articles is 13 (combating climate change), followed by SDG 15 (supporting life on Earth) and SDG 1 (eradicating poverty). The SDG with the highest number of related articles is number 13 (combating climate change), followed by SDG 15 (sustaining life on Earth) and SGD 1 (eradicating poverty).

To assess the relationship between bioeconomy and SDGs 1 and 2, we did a correlation analysis of one of the region's key bioeconomy sectors, LAC countries, biofuels, and food security. The inclusion of this sector was determined based on the availability of historical data in the nations to undertake the study concurrently for a typical year. According to our statistical estimates, biofuel production in the LAC nations investigated has a significant negative relationship with the frequency of malnutrition, CO2 emissions, and population growth. Conversely, there is a positive relationship between net capital stock, food production per capita variability, and food output. Based on our findings, we conclude that the biofuel sector can promote economic development in the LAC regions by leveraging the area's biomass potential, creating new opportunities for various stakeholders in the countries; however, it is essential to consider the environmental aspects of its production as well as clear governmental policies to ensure food supply.

For the relationship between bioeconomy and SDG 5, we evaluate the gender policies and gender parity in scientific production in the LAC region. In the case of the gender policies in the bioeconomy

instruments evaluated in nine countries, a specific focus on gender inclusion reflected as a high-level priority, strategic focus, objectives or plans and programs is found in Brazil, Mexico, Paraguay, and Costa Rica. For the remaining countries, gender equality is a national focus in their bioeconomy framework. It is vital to note that the abovementioned results do not imply that the other countries in the region do not have policies or instruments that approach gender equality; however, these are in their national strategies in different economic and social aspects. For gender parity in scientific production in the LAC region, we determine, based on a correlation analysis, that a direct positive correlation exists between the investment in R&D and the percentage of women researchers. In general, we can argue, based on the analyses carried out, that there are very few bioeconomic instruments in the region that have gender equity as a priority despite being a fundamental issue when we talk about sustainable bioeconomic models. Although it was not possible to make a direct assessment of the percentage of women researchers in the areas of bioeconomy in the region, in general, we can see that there is a direct impact on investment in R&D and the percentage of women in research and an indirect negative correlation with the number of women and GDP invested in education. This reflects the pending task that countries have in reducing the gender equality gap by promoting actions and strategies that involve women in a more significant proportion in the development of the bioeconomy.

Finally, we consider it important to provide a case study in a Latin American country such as Ecuador to measure the impact in three dimensions of sustainability in a specific potential bioeconomy sector as bamboo, which in that country is used for several purposes but especially in construction. Through the sustainable life cycle assessment, we determine that the bamboo subproducts evaluated in the specific product life analyzed are environmentally, economically, and socially sustainable compared to other timber products used in construction. Bamboo is one of the non-timber products used for centuries in rural communities for infrastructure without the proper treatment or preservation. However, this material has immense potential in every sense that needs to be considered if we discuss sustainable bioeconomy material for construction in LAC countries.

5.1.1. Hypothesis corroborations

- Hypothesis 1 was fully demonstrated as bioeconomy sectors for the Latin American and Caribbean region were identified and their macroeconomic importance in various nations. However, the lack of consistent updated data allowed the economic study of certain countries in the region.
- Hypothesis 2 was verified since studies on the supply and demand side of the bioeconomy sector's importance in Latin American and Caribbean countries are based on primary value-added products and bioeconomy services. In this sense, the national accounts could not identify products and activities related to high-value bioeconomy sectors.
- The corroboration for hypothesis 3 was not entirely fulfilled because, in an ideal scenario, an overview of the interaction between most SDGs and bioeconomy sectors in the LAC region would be appropriate. However, due to a lack of comparable historical and standard data, we were able to select some SDGs where data was available to conduct various studies and investigate the relationship between distinct bioeconomy sectors. As a result, the findings cannot be extrapolated to a general reality of the region.
- The hypothesis 4 was supported since the correlation analysis revealed a negative correlation between certain independent variables, such as the frequency of malnutrition, CO2 emissions,

and population growth. On the other hand, there is a positive correlation between the food production index and net capital stock.

- Hypothesis five was partially corroborated as the evaluated bioeconomic instruments were scarce and did not reflect the reality of the entire region. Likewise, it was impossible to obtain specific data on the contribution of female researchers in the field of bioeconomy, which is why the results were generalized as a percentage of female researchers.
- Hypotheses 6 and 7 were fully demonstrated, as the results evaluated this chain's environmental, economic, and social impacts within a specific bioeconomic product in Ecuador using the sustainability assessment methodology.

5.2. Recommendations and future directions

Because one of the main limitations of the current research was the extraction of historical uniform datasets for Latin American and Caribbean countries, we recommend that future studies limit the scope of the research to specific countries where data is readily available to perform the various analyses required. Since the bioeconomy sectors aggregate distinct economic subsectors, future research can focus on analyzing a single subsector to gain more direct access to data and make appropriate evaluations.

The bioeconomy as an economic model is still being developed in the LAC region, with some nations having specific plans and mechanisms to implement it. However, the prioritization of the bioeconomy sector is determined by various circumstances and institutional conceptions in each country, making it more difficult to standardize the classification of the aforementioned sectors. In future research, we recommend thoroughly analyzing each country's national or regional instruments to concede a standard interpretation of the bioeconomy sectors that can be applied to every region.

One of the main transversal axes of bioeconomy concepts and sectors is their relationship with regional sustainable development; thus, we conduct the final part of our research by evaluating the relationship between the Sustainable Development Goals and the bioeconomy in the region through specific analysis of certain SDGs. However, we advocate a more comprehensive analysis, given that practically all SGDs directly impact the bioeconomy.

One of the challenges of measuring bioeconomy in LAC countries is the lack of a standardizing methodology for determining which products and activities belong to the bioeconomy; that is why, through the case study of bamboo used in Ecuador, we believe that the Life Sustainable Cycle Assessment can approach economic, social, and environmental measures to determine how sustainable a specific value chain can be. We recommend using this methodology to get more direct data on the contribution of crucial bioeconomy sectors in countries.

5.3. Limitations

One of the most prominent limitations of the current study was the absence of a uniform economic, social, and environmental historical record for Latin American and Caribbean countries, which would aid in analyzing and estimating the relevance of bioeconomy sectors in different countries. The current study could not develop a standardized number of nations or a year foundation for conducting various types of research among the 33 countries in the LAC region.

Given that there is no standardized concept of bioeconomy sectors in the region and that most countries lack a specific instrument or policy framework for bioeconomy development, the bioeconomy sectors in this research were determined based on the secondary information evaluated and the author's study criteria.

The scope of the research issue is broad, making it challenging to gather specific and uniform data for all of the region's countries. To address this issue, we conducted several evaluations, ranging from the broad spectrum to individual sectors, to assess the impact of the bioeconomy in various sectors and countries within the area. We know that the data obtained in this research cannot be generalized to the reality of each country in the Latin American and Caribbean region since every nation has its peculiarities, potentialities, and mechanisms for defining its bioeconomic sectors.

5.4. Policy Implications

Unlike the European Union, which has created monitoring frameworks for bioeconomy advancement, the Latin American and Caribbean region lacks standardized economic valuation procedures. This constituted a constant issue in the current study, both in classifying bioeconomic sectors and evaluating their economic significance, because government records were often fragmented or outdated. Therefore, governments need to standardize the definitions of bioproduct-based sectors and generate regular reports on the bioeconomy's contributions to GDP, employment, trade, and sustainability metrics.

Disparate the European Union, where bioeconomy is a high priority despite limited natural resources, Latin American and Caribbean authorities have not entirely embraced bioeconomy as a strategic goal. International collaboration, information sharing, and alignment with global bioeconomy trends are required to strengthen LAC's position.

The study reveals that most LAC countries focus on low-value bioeconomy sectors. Government policies can encourage industrial upgrading by rewarding high-value bio-based production, notably in the biopharmaceutical, biochemical, and bioplastics sectors.
The bioeconomy has enormous potential to drive sustainable development in LAC, but achieving the SDGs will require targeted policies that ensure economic growth, environmental sustainability, and social inclusion. To maximize the bioeconomy's contribution, policymakers must establish regulatory frameworks, financial mechanisms, and regional collaborations that enable the region's sustainable development.

The study emphasizes the possible trade-offs between biofuel expansion and food security, particularly in countries that rely primarily on staple crop exports and lack specialized laws that address the sustainable aspects of biofuel production.

The study found that bioeconomy policies in the LAC region have few gender-specific strategies. Therefore, it is important to ensure bioeconomy policies that include gender-sensitive approaches, such as equal access to education, training, and entrepreneurship opportunities.

According to Ecuador's Life Cycle Sustainability Assessment (LCSA), bamboo products have a lower environmental impact than conventional wood and non-renewable materials. Furthermore, their societal influence is more significant than the norm. As a result, bamboo presents a strategic

opportunity for LAC countries seeking economic diversification, environmental sustainability, and rural development. However, achieving its full potential necessitates integrated policies that promote industrial development, market access, and cross-border cooperation.

Finally, to help harmonize and standardize the data availability of bioeconomy in the region, we recommend the implementation of a centralized observatory or a similar body, which supports the standardization metrics across LAC countries, improves data availability, and tracks the bioeconomy's contributions to GDP and sustainable development goals. It is also essential for the region to adopt a step-by-step approach to harmonize national bioeconomy policies. This could be done by using shared frameworks, capacity building of national institutions, and regional knowledge-sharing platforms to align methodologies while respecting local realities and existing strategies of each country in the region.

6. NEW SCIENTIFIC RESULTS

- Within the classification of bioeconomic sectors in the region, the services sector emerged as the leading contributor to bioeconomy value added in the eleven countries under study, followed by value-added primary industries and the primary sector. The study could not reflect the high value-added bioeconomic activities. This is due to the lack of economic detail in the national accounts to assess their financial contribution in GVA.

- The study revealed a significant data gap in historical economic records across the region. Only 11 out of 33 countries could quantify the bioeconomy sector's contribution to gross value added, thereby limiting a comprehensive assessment of their economic significance.

- This study suggests that most scientific studies of bioeconomy in the region are relevant to nearly all sustainable development goals, as sustainability is one of the cross-cutting axes of bioeconomy.

- Based on a statistical data analysis of different variables in the countries studied, the study shows the specific relationship between the sustainability considered by specific SDGs and the bioeconomy sectors.

- In the first analysis, the study finds a substantial negative link between biofuel production and food security factors in LAC nations, as well as the incidence of undernourishment, CO2 emissions, and population growth. In contrast, there is a positive association between net capital stock, variability in food output per capita, and food production.

- For the second analysis of the relationship between bioeconomy as a general approach in the region and SDG 5 (gender equality), only a few countries include gender inclusion approaches as a high-level priority, strategic focus, objectives or plans, or programs in their bioeconomy instruments. Although it was not possible to directly assess the percentage of women researchers in the bioeconomy in the region, we can see that there is a direct impact on investment in R&D and the percentage of women in research in LAC regions, as well as an indirect negative correlation with the number of women and GDP invested in education in the countries evaluated.

- For the third analysis, we demonstrate that the Sustainability Life Cycle Assessment can be a proven methodology to evaluate the three central axes of sustainability in a specific value chain of a bioeconomy activity; in the case of the current study, we assessed the use of bamboo subproducts as part of the primary value-added sector in one country in the LAC region.

7. SUMMARY

This study assesses the significance of the bioeconomic sectors in one of the world's most natural capital-endowed regions, owing to its vast biodiversity and natural resources. Latin America and the Caribbean are areas made up of 33 developing countries, and they have the most significant biomass production in terms of natural resources, such as soil quality and available land. The Bioeconomy is an alternative model for sustainable development and green growth in the Latin American and Caribbean region. It allows it to minimize reliance on fossil fuels, assist the green energy transition, and encourage biological resource production and knowledge-intensive utilization.

The purpose of this study is to depict the importance of bioeconomy sectors in the LAC region from several perspectives on sustainable development. To this end, we set out three essential research objectives: a) to analyze the most relevant bioeconomy sectors developed in the region in the last decade, b) to determine the economic importance of these sectors, taking into account the information available in official databases, and c) to understand the sustainable relationship of bioeconomy sectors with respect to essential aspects such as food security, biomass production, innovative initiatives, and scientific gender product.

The author used mixed methodologies to answer the study questions. These methodologies combine qualitative and quantitative research approaches, concepts, and data analysis in a single study. Among the mixed method strategies, the author used concurrent mixed methods, which combine quantitative and qualitative data to examine the researcher's research question.

As a result of this research, the first part defined the following sectors as important sectors of the bioeconomy in the region: primary, primary value-added, high value-added and bioeconomy services. In the second part, it was established that within these bioeconomy sectors, the services sector is the sector that contributes most to gross value added in the eleven countries analyzed, followed by high-value-added primary industries and, in third place, the primary sector. It was not possible to identify the economic importance of the high-value-added sector in the region.

In the first analysis, we observed that most of the SDGs are related to the region's bioeconomy. In the second analysis, we determined a direct and indirect correlation of biofuel production with three variables related to food security in the region. In the third analysis, we determined that very few countries in the region include a gender approach in their bioeconomy strategies. The correlation between the number of female researchers in the region is directly influenced by the resources that governments invest in research for development. In the fourth analysis, we apply Sustainable Life Cycle Analysis to a specific value chain in Ecuador as a case study of the valuation of the social, economic, and environmental impacts of a primary value-added bioeconomy material such as bamboo used as a construction material.

Finally, we have made several recommendations and prospective directions for future research on this topic, which is quite wide and can be narrowed down to different specialized areas in order to have more up-to-date data and be linked to the potential of each country in the region.

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10. APPENDIX

10.1 Interview 1

IICA/ BIOECONOMY PROGRAM
Hugo Chavarria
Director of the Hemispheric Innovation and Bioeconomy Program

Question 1: Considering IICA's experience in the field of bioeconomy and the concept of sustainability that this economic model involves, do you consider it an alternative development model for the countries of the region?

The LAC region almost takes external formulas that others built in history for regional development that are not necessarily efficient and solve critical problems. The bioeconomy is the only model we can use to create successful development by ourselves from our comparative advantages since the primary input of the bioeconomy is biomass resources, and the region is one of the most biodiverse regions. For example, 50% of the known biodiversity worldwide is on 15% of our territory; the region possesses 25% of the forest in the world, 17 megadiverse countries are in LAC countries, and other advantages. This new model is based on our comparative advantage, which responds to our needs and potentialities. This version sounds perfect for a PowerPoint presentation, but in reality, it is super tricky since we need to take advantage of these potentialities. From this, 50% of the biomass, just between 20 and 30%, is mapped and identified. We know what is helpful from the eight megadiverse countries. In the majority of them, we did not invest in bioprospection. We have yet to learn what we have in our forest and what type of use we have given them; the Europeans are waiting to do that instead of us investing and doing it to capitalize on our natural resources.

Questions 2 and 3: What do you consider the most critical bioeconomic sectors in the region? What non-traditional bioeconomy industries do you believe have economic, social, and environmental potential?

For him, the Bioeconomy should have four essential characteristics.

a) origin from biological resources
b) incorporation in a high degree of science, technology, and innovation
c) It should contribute to the value added to products, not the primary products, or, as a concept, "Integral biomass cracking."
d) and compulsory should contribute to a sustainable environment and decarbonization

There are already two sectors of the bioeconomy in the LAC region that have already been installed: biotechnology applications for agriculture and biofuels, which have been remarkable for the area for at least 30 years. However, in the case of biofuels, their importance can be improved. In Brazil, the percentage of the mixture of biofuels and fuels is 27%, while in Argentina, it is 20%, and in Colombia, it is 12%. Still, this sector could escalate if these countries develop technology to fuel the aviation sector.
However, some sectors have enormous potential, and everyone talks about it. Still, there are no concrete actions to give them impulse, like products from local biodiversity (biocosmetics, superfoods

from insects, among others). In the LAC region, two countries have bioeconomy strategies: Colombia and Costa Rica; in the case of Colombia, the base of its strategy is bioproducts from the potential Amazonia resources, national parks, and biodiversity, like biocosmetics, and they create some national Institute to work in this calls “Sinche Institute” also in Ecuador there is something related to it, in Brazil, it calls “INPA," Peru as well and in Costa Rica calls “INBIO.”

All of these institutes were created to identify the local biodiversity that can have marketable value and generate products with the local communities to help them export or make agreements with big companies with enough capacity to take advantage of these resources sustainably. There are only a few successful cases of this type of work. One example is the ASAI, which is a palm tree that has enormous potential and is marketable. Still, for sure, in the forest of the region, we have thousands of trees and plants with a significant potential that has yet to be studied.
In summary, in the LAC region, we have already studied sectors with results demonstrated 25 years ago, such as agriculture and biofuels. Others are in "baby steps” but can be considered the bioeconomy of the future, like the bioproducts from local biodiversity; another sector with immense potential is biorefineries from residues. Unfortunately, this technology is only partially developed; at the moment, we are developing this technology, and the region will have a breakpoint in the development of the bioeconomy. Nowadays, we are doing small initiatives with crop residues from coffee, orange cacao, and avocado; some companies are working on that, but the technology used is not that efficient to escalate this bioindustry and make them more efficient can represent an inflection point for the local development.

Furthermore, there is an intermediate sector known as "bio inputs" in which the region has 20% control in the global market, especially for the biocontrollers, and it is expected that in 10 years, LAC countries will be the biggest producers of biocontrols in the world. It is only produced by one country, Brazil (between 60 or 70% of the production and consumption is in this country). However, other essential countries are interested in this sector, like Nicaragua, which has a national bio inputs strategy, and Peru, which will build the region's most considerable Bio inputs plant.
One of Brazil's advantages is the regulation for bio inputs since it is very flexible and efficient; it is possible to register a new bioproduct and start selling it in the market in only a few days. Brazil's biofabrics produce these bio inputs, register them, and commercialize them with big agriculture providers. Even in some cases, big Argentinian Companies such as Rhizobacteria, which has one of the most advanced technologies in the region, register the product in Brazil since it is easier than in Argentina.

Brazil is the only country that has bio inputs for mono-crops. Usually, this type of product is designed for niche markets. So, this bio-inputs sector is the intermediate sector that is less important than biofuels. Still, it can be, especially in a few years since it has already proven results.
According to the IICA definition, the services sector only fulfills two of the four conditions of the bioeconomy since the monetary value of Latin America's services is still to be determined.
Some regional entities, such as IICA, are working on the first steps in agritourism to valorize all the resources in the farms in the local territories that the tourism suppliers can incorporate into their offer.
Some countries (mining countries) produce minerals using bio inputs to decontaminate the lands. This process is called bioremediation, where you use microorganisms that feed on heavy metals, and after some time, this land can be recovered and productive again. Also, this process can be considered a service, but the region is still taking baby steps in this area. Regarding measuring this service sector, indicators are difficult to measure.

Question 4: What are the constraints in the region's countries in developing and implementing bioeconomic strategies?

g) Position of the bioeconomy concepts in the decision-makers in the region: Lack of convincement of the decision makers; Europe has less than 16% of the natural resources in the world (LAC has almost 50%), they give a high relevance to Bioeconomy, while in LAC region we are paying attention to not so relevant topics without consider topics in larger and long scale, since this person in charge of the keys institutions are for short periods without and institutionalist of the policies. For example, IICA, when they have meetings with the Agricultural Ministries of the region, do have yet to discuss big topics since those are very ethereal or far from their realities.
h) The LAC region cannot take advantage of its capacities: we have an enormous biological resource that we do not know what is possible to use since most of the countries in the region do not have bioprospection projects
i) Lack of Investment and scaler of new solutions for bioeconomy: Nowadays, there are many youngsters in incubation projects and a large number of startups; however, when these people have a prototype that needs to be scaled in a real business, there is a lack of investment for it. For example, Europe has important regional projects to provide this type of investment in the member countries; in the LAC region, there is no single infrastructure for scaling and accelerating bioeconomy prototypes. R&D institutions, including universities, have small funds that are not representative of bioproducts. For example, small startups and researchers in the region have innovative products from bio residues that try to export their products on a big scale, but this is impossible because their production capacity is insufficient.
j) Regulations and Normative for Bioeconomy Initiatives: For example, if you want to register a biofertilizer, the process can be super slow, and it is probably impossible to get the certification since the governmental institutions do not have any normative or protocol to apply, evaluate, measure, or categorize this product. In conclusion, countries must be prepared to regulate biological bioproducts, increasing the cost and time. In contrast, chemical products take three times less than registered biological products. More institutionalization is needed to regulate and subscribe to biological products.
k) Universities' research needs to respond to the necessities of the industry: this kind of research that takes advantage of potentialities and resolves problems usually takes much work to find. In most cases, the study is disconnected from the market necessities. On the other hand, some infrastructure and equipment had been purchased, but no one uses them due to a lack of funds to maintain them. There needs to be more connection between the infrastructure and equipment, the universities' research, and the bioeconomy sectors' potentialities. Most researchers are not interested in publishing articles that can be scaled to spin-off solutions for bioeconomy.

Question 5: Are regional indicators necessary to quantify the importance of the bioeconomy in the region? Do you know a country that is developing a measurement methodology?

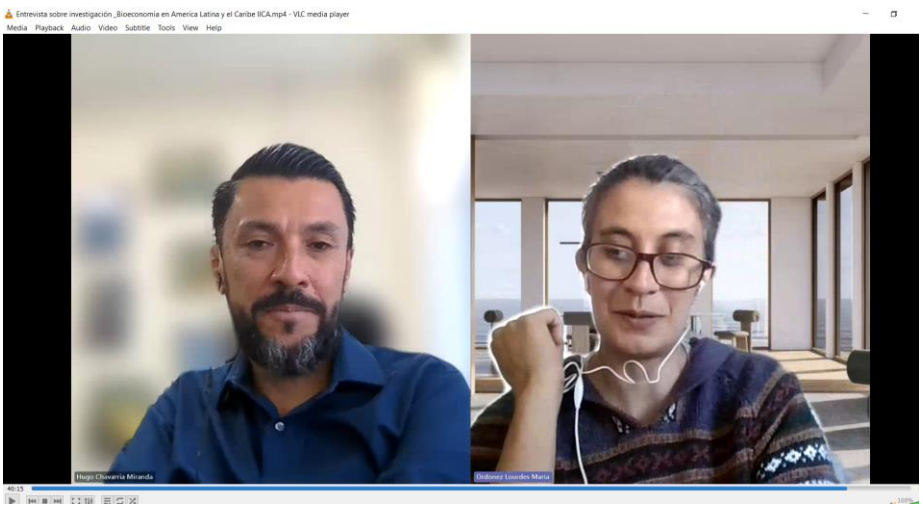
The data available in LAC do not allow us to apply stricter methodologies to determine what sectors are directly related to the bioeconomy, its weight, and its links with the different economic sectors (linkages with other sectors).

So, in the countries' national accounts, you have the big "national accounts" like cacao, rice, plantain, industries, tourism, etc., which force us to select by a personal criterion which is part of the bioeconomy. These methodologies have severe limitations due to incorporating sectors originating in biological resources that need to be value-added or biotechnology-incorporated.
The United States launched its measurements of bioeconomy sectors based on their criteria for their economy, which are different for the LAC region or other countries. For the US, the bioeconomy products are the ones that have biological bases that incorporate biotechnology.
Another problem of LAC regional data is that the information needs to be harmonized, making comparing countries difficult.
One of the methodologies developed by IICA in the past years was based on the "Grange Matrix" or (Input, Output) tables, which measure how much one activity sells to another. The multipliers of the grange are removed to measure the impact of the bioeconomy on the other sectors with a cascading effect when there is an external impulse.

Question 6: How much is invested in R&D in bioeconomy sectors in the region?

In the case of the budget for R&D, that can also be considered part of the service sector. For example, the LAC region invests around 1% of its agriculture GDP in biological research, compared with Europe, which is around 4%. However, determining the impact of these values on actual activities takes much work. For example, IICA has been working in bio entrepreneurship, and when they evaluated from this research activities, how much goes to applying solutions in real concerns is to small proportion since the primary research or the applicative one is not connected with the necessities of the industry. So, these R&D indicators tell almost nothing.

Photographic evidence of the interview:



10.2 Interview 2

Secretary of the Biofuels Coalition
Dr. Augustin Torroba
International Specialist in Biofuels

Question 1: Taking into account that biofuels are one of the most relevant sectors in economic terms and in terms of importance in some countries in the region, what do you think are the main challenges for the sector?

The first point is that the region is one of the world's most developed biofuel production. When we speak of biofuels, we must consider the liquid ones: bioethanol and biodiesel. Nowadays, the first one is 2/3 of the production and consumption, and the rest is for biodiesel. Considering the previous statement, Latin America has an extensive tradition thanks to Brazil, which was the first country to start with a mixture of regular fuel and biofuels in the 70s with a program named Pro alcohol.

Secondly, the region is one of the biggest exporters of raw biological materials that other countries convert into biofuels, and it imports significant quantities of petroleum derivates; only a few countries import, including Venezuela. From this premise, the area can produce biofuels from the extensive raw materials on the continent. When we talk about the challenges, one of the strengths is the lack of institutional frameworks that are solid and stable at the same time, especially when biofuels need different mandates.[3].

To maintain their competitiveness in comparison with fossil fuels. For example, biodiesel is now more expensive since the raw material from where it is extracted, like soy oil or palm oil, is expensive nowadays, at approximately 1200$ per liter. At the same time, five years ago, it was half, which respectively increased the price of biofuels.

The subsidies, almost 4 points of the world GDP, go to subsidize fusil fuels (study of the World Bank), and is one of the barriers to renewable energy development within the biofuels are part of. Most renewable energy sources do not have subsidies; what usually happens is that the governments implement a mechanism through mandates that decide the percentage of renewable energy in the national energy matrix or the percentage of biofuels in the national fuels matrix that the people who commercialize it have to follow. How this mechanism operates depends on the country's regulations. Some countries fix the price of biofuels, or in other cases, there are free prices in the market, and what petroleum companies do is charge the consumer for those biofuels according to the cost of the market compared with fossil fuels. Also, other countries like Brazil have complementary policies where biofuels are of higher quality and use more technology. When the customer goes to a gas station, they can choose between biofuel mixed with fossil fuel or pure ethanol according to the price.

Question 2: You consider that biofuels have negative environmental considerations (land and water use) that need to be considered to make the sector more sustainable in the long term.

There are already different tools to tell if biofuel is sustainable; most countries are working in this direction to measure these impacts, for example, with methodologies like the life cycle assessment,

[3] Mandate refers to the political instrument regulating the proportion of mixture between biofuels and fossil fuels in the country's fuel composition for customer commercialization

hydric footprint, etc. For example, to export biofuels to the European Union, it needs to demonstrate many parameters such as reducing at least 60% or more gas emissions than fossil fuels, zero deforestation, and lower impact on land use—the same parameters applied in other countries like the US, Canada, Brazil, among others.
However, the floor to measure sustainability is super high (that should be like that). Still, it differs from fossil fuels and has few barriers to commercialization among the countries. So, I consider we need to be more practical, especially in regions like the European Union, for example as a methodological approach, when you are evaluating biofuels, you go through the whole cycle (LCA) from the gate to the cradle, while in the fossil fuel only is evaluated the fuel combustion since the other process involved are analyzed separately. The more practical way to achieve green sustainability is to work on carbon taxes with some differences between the countries.

Question 3: Is the region working on generating second and third-generation fuels?

When talking about second-generation biofuels, we refer to sources that don't compete with agricultural ones. For third-generation biofuels, those produced with algae, the region has undoubtedly advanced, at least for now and in the middle term, mainly due to the lack of technology to generate them. In these 30 years, we did not.

There is a hot debate around second-generation biofuel, especially regarding the change in land use from agriculture to food crops, which is also changing the regular use of the land. Nowadays, globally, the production of second-generation biofuels is marginal, and the region also has low production. However, we have countries such as Brazil that produce second-generation biofuel from sugarcane crop residues; the government has two biorefineries working on it from the 350 they have, which also represents cost benefit for the producers since it can be used for other purposes. I believe this biofuel will be marginal for at least the next 20 years until the region has enough technology.

Something that is not considered second generation but is important is the use of cooking oil residues for biofuels instead of being wasted and contaminating the environment's water resources; some estimations show that between 70% and 80% of cooking, oil recovery can be destinated to biodiesel production.

Question 4: What is the role of the Biofuels Coalition Secretariat in the institutional policies of the countries in the region regarding biofuels?

The Biofuels Coalition Secretariat was born as the IICA initiative, which calls the private sector, chambers of commerce, companies, associations, NGOs, etc., which aims to produce and consume sustainable liquid biofuels in the LAC region. Also, this Coalition has as an objective positioning these Secretariat in international spaces such as the COP, promoting effective communications of renewable energy (a complex topic sometimes). It also creates synergies between public and private stakeholders, where the governments have a crucial role.

The Coalition and IICA support countries interested in building policies and frameworks for biofuel production, especially those that need more human talent, because these are new topics for certain countries. In conclusion, the Coalition becomes a provider of public services and direct consultancy to make specific technical policies or norms to promote renewable energies, such as the reference values for biodiesel.

Not in all the countries are the constructions of this norm easy to work with; however, we had significant advances in Central America, where we trained technical public workers and stakeholders in different events; now we are more focused than in countries in Central America from Mexico to Panama since this one does not have any political instrument for biofuels. However, in the south cone of the region, we are working on more specific themes like biofuels for the aviation sector.

Question 5: To which sectors do you think biofuels in the region can scale up their commercialization markets?

In the literature, you will find something called SAF (Sustainable Aviation Fuel) that needs to fulfill three requirements: first, be a fuel that accomplishes quality standards, that is made for the aviation sector, and that comply the sustainable concept of CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation), this last normative is the one that determines the basic requirements that sustainable fuels need to fulfilled for the aviation industry. For example, these fuels need to reduce at least 10% of gas emissions compared with fossil fuels, fair trade, labor, hydric footprint, etc.

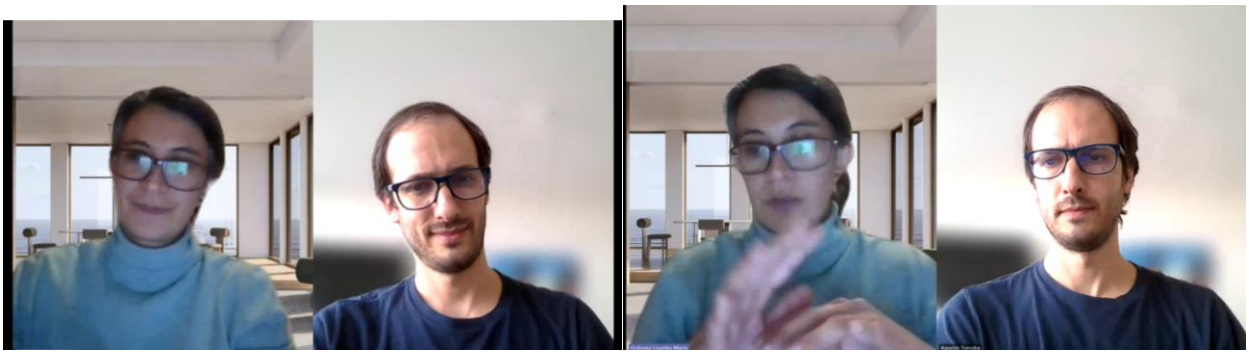
To produce this type of fuel, 11 technological routes exist; in most cases, the input comes from raw biological materials that, in the end, we know as biofuels for aviation or bio-jet. For this purpose, it uses the same raw material of biofuels inland transport, especially the fatty acids that produce bio-jet in a technological route known as HEFA (hydrotreated fatty acids); other raw materials used are sugars and starches, which produce alcohol in the technological route known as ATJ (alcohol to jet) and generate biofuels for aviation which is more sustainable than fossil fuels.
So, with all these raw materials, the region has enormous availability, and the value chain is significantly developed for oils and alcohol, which is a great opportunity and potential for the area since the aviation industry plans to have net zero emissions until 2050. To achieve this goal, almost 60% of the gas emission reduction should come from sustainable aviation fuels or SAF since it is tough to develop biofuel from other sources like hydrogen in the aviation sector. However, unlike the EU, the USA, and some Arabic countries, the region needs public policies to promote these sectors.

Question 6: How much is invested in R&D in this sector? Moreover, what topics should research be done on?

It is difficult, but I will give you an example to explain it better: The Energy Department in the US invested a couple of million dollars in algae to generate biofuels, and the main conclusion was that it is almost impossible to develop biofuel from that material. However, it can be helpful for different purposes. So, some countries can afford to invest in this type of research, and others need more budgets in the LAC region.

In general, biofuels will be the source of innovation in the aviation sector since essential investments in research and applicable technical developments will improve the process of escalating commercial routes, defining new technological routes, or patenting them.
Another topic is maritime biofuels; the region is taking baby steps in this aspect. However, in terms of other bioproducts, there exists a significant investment in ethanol and fatty acid for new uses like bioplastic, ethylene glycol, and biopropylene. In conclusion, there is a new wage for technological advances to produce bioproducts to replace petrochemicals, to give a turn in the value added in biofuels to generate this subproduct. Brazil is making more investments in this area, which has a more substantial private investment; for the rest of the countries, there is no significant investment in this initiative.

Photographic evidence of the interview:



10.3 Interview 3

REDBIO (Network of Biotechnology Laboratories for Latin America and the Caribbean)
Dra. Sandra Sharry
Second member of the board/ Advisory Commission to the Secretary of Agriculture/Member of the National Biotechnology Commission

Question 1: What are the main bioeconomy sectors that have potential in Latin America and the Caribbean?

There are three different scopes for bioeconomy: the ones linked with biotechnology, the eco focus based on biodiversity, and the focus based on biomass production. In this sense, Argentina and Brazil can transit in any of these scopes since they have considerable biodiversity and are well developed in biotechnology; now, for other countries like Ecuador, Colombia, and Costa Rica, the path is focused on biodiversity. It is also essential to differentiate the low-tech bioeconomy from the Hight tech bioeconomy; you have in the LAC region countries that are low-tech and others with both high and low tech like Argentina and Brazil, so it is important to differentiate the countries at a national level and in local one to understand the reality of bioeconomy in the region.
The definition of bioeconomy for Latin America and the Caribbean is still under discussion since each country prioritizes the importance of the economic sectors within these national policies.

It is important to point out that biotechnology is one of the ways to insert innovation into the bioeconomy products, and also other ways to add value to these products that make them sustainable during their life cycle, taking into account the 4 R concept (Reducing, reusing, recycling and recovering), for example, the value-added base on biodiversity of the forest for non-timber species that produce (fibers, biocosmetics, food, honey, etc).

In the case of Argentina, the country has had a national strategy for bioeconomy since 2012, where all the baseline information and bioeconomy sectors have already been identified with a special focus on biotechnology. Nowadays, the country has a specific program called bio development, coordinated by the Bioeconomy Secretary (former Agriculture Ministry). In this national document all the sectors are identified, including regional areas where the bioeconomy strategies need to be applied and the economic contribution of these sectors; everything is mapped and documented by the Ministry of Agriculture and the Ministry of Science and Technology. The country has clear public policies for bioeconomy with significant funding for different projects and programs.

Question 2. What initiatives will REDBIO undertake to promote the development of these sectors?

REDBIO is a cooperation network born as an FAO initiative that works in biotechnology for Latin America and the Caribbean; it was established in the '90s and consolidated as a Biotechnology Laboratories and Research, which nowadays includes companies. The network has different chapters per country; within it, a focal point is responsible inside the countries for organizing different activities. Also, it has an international wing that articulates actions across the countries. For Argentina, the chapter of REDBIO is very consolidated and organized. REDBIO has meetings every three years, and the network's current president is from Colombia. Every year, REDBIO organizes a workshop to discuss different topics, bringing expertise from other parts of the world. In general, the network works

on everything related to biotechnology, emphasizing new breeding techniques from the point of view of scientific advances.

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Question 3. Which potential bioeconomy initiatives REDBIO believes should be investigated

Argentina is an agro-exporting country; therefore, the bioeconomy initiatives will focus on the primary sector, especially now that the central institution working on it is the Ministry of Agriculture. Now, the country has identified many different bioeconomy sectors, such as forestry and diversity. The last one, biodiversity, is recognized as a potential for the LAC region, and here, you can distinguish Brazil and Argentina from the rest of the countries that work intensely in biodiversity and biotechnology. In my particular case, I have an emphasis on biodiversity in products from non-timber forest resources, mainly focusing on native forests, agri-food systems based on forest ecosystems, and vulnerable communities (indigenous, young people, women, and so on); in other words, inclusive bioeconomy. This is the type of bioeconomy that the LAC region should focus on since it is part of our permanent problems like poverty, food security, eco-diversification, etc. The bioeconomy for the LAC region should have a totally different focus than that of the European one. One challenge is finding the correct focus in each country's areas.
Argentina and Brazil have big developments in biofuels and biorefineries, and there is a lot of research and innovation in between. Also, there are initiatives around bioplastics. So, in Argentina, groups of researchers in different regions work on this topic.

Question 4. What are the main challenges facing the region in developing the bioeconomy as a model for economic development?

The LAC region is enormous, so the challenges change depending on the country. From my point of view, the bioeconomy difficulties are at the local level. Without regional development, you do not have a bioeconomy. In the case of Argentina, since the country is vast and diverse, the challenges will differ in each region. For example, if you go for a particular area, the strength is the forestry sector; if you go to another, biodiversity, or in other biorefineries or livestock production, etc.
To generalize, the main barrier to developing a bioeconomy in the region for any country is funding (economic resources). As LAC countries, we do not have any restrictions on human resources; we have human talent with enormous capabilities, and even in some countries, like Argentina, the infrastructure is also well-developed.

Question 5. Which potential bioeconomy initiatives REDBIO considers should be investigated

It is impossible to generalize the bioeconomy initiatives that should be researched in Argentina since it is a big country with different initiatives and a very diverse country with strengths in each region. Regarding biotechnology, Argentina has had a national policy since the 80s. Therefore, all kinds of research and initiatives are done in this field in different species of animals, plants, micro-organisms, trees, etc. As Argentina, we are in another chapter compared to other countries in the LAC region. Every day, the National Commission of Biotechnology checks the protocols of different modified products to be liberated into the market. Argentina has the most updated new breeding regulation globally (we have apparent protocols to determine what is modified). The current regulations do not restrict genetically modified organisms, and the international organism as FAO recognizes all these policies and regulations.
Another important criterion was that the communities around the regions in Argentina participate actively in the meeting to build the national plan for the bioeconomy.

Question 6. What is the role of universities and researchers in implementing bioeconomy initiatives that contribute to developing the countries in the region?

Argentina is a big country with different necessities and immense biodiversity; mainly, the universities in the country are public institutions with high standards and enormous scope, while the private ones are of lower quality. So, it is not easy to generalize the role of the universities in the implementation of bioeconomy initiatives since it will depend on the type of university and the region where it is located, among other factors. Since the country started to build the national bioeconomy strategy, one of the main activities was organizing bioeconomy meetings in each region where academia participated actively in government initiatives. For example, the previous year, I had to evaluate the regional development plans of the country, and bioeconomy and biotechnology were a priority topic that included different stakeholders like the universities. In other words, national policy is the framework that provides funding for bioeconomy projects for universities in R&D initiatives. Since 2012, the bioeconomy has been a national priority, anchored firmly in biotechnology, since the country has had a significant development in these areas and strongly focuses on the primary sector.

Photographic evidence of the interview:

10.4. Interview 4

Inter-American Development Bank
Dr. Rafael Anta
Specialist in Science, Technology and Innovation

Question 1. Based on your experience and the scope of IBD, do you consider the concept of sustainability in the bioeconomy sectors a good alternative for the development of the LAC region?

The answer is yes, the sustainable bioeconomy is an option for the region's development, but explaining this affirmation with more concepts is essential. The bioeconomy already existed a long time ago. Still, it was not called a bioeconomy since the bioeconomy is understood as an activity based on the use of biobased renewal resources with significant untapped potential. So, based on this statement, the LAC region has always been criticized since it has a lot of natural resources (biological and non-biological), and what has been done is sell them to the other areas without adding value. Here, the bioeconomy is a big challenge since an essential concept of the bioeconomy is the value added to the biobased resources. LAC region has the pending task of transforming what the soil produces into something with more value added. The economic importance of the bioeconomy is minimal, even though there is no standardized regional system of national accounts to measure it. Still, the potential is enormous, and the work of BID is to help the countries take advantage of these opportunities.

Question 2. In addition to biofuels, which are a developed sector in some countries in the region, what other sectors do you identify as having potential for local development in the LAC region?

It is important to understand that the bioeconomy sectors should incorporate biotechnology; for some countries, the primary agricultural sector and nature tourism are bioeconomy and are not part of it. For BID criteria, the concept of bioeconomy is more straightforward: it is an economic activity based on the use of biological renewable resources and their transformation to add value; this additional value can be achieved by chemical processes, biotechnology, and mechanics, among others. Considering that there can be low- and high-tech value added across all of these activities.

So, to answer your question based on the previous criteria, biofuels are already an essential sector in the region, with Brazil as a pioneer country, followed by Argentina and others. To illustrate the concept of bioeconomy sectors, let us imagine a pyramid where biofuels are produced in higher volumes and at lower prices at the base. This is why it could be considered a commodity with no significant technological challenges, maybe some scaling up in second and third-generation fuels, but no more than that. That is why, as IDB, we have no direct action in Brazil, for example, in this sector because it is highly developed.

If we continue with our pyramid example, bio-inputs is a second sector that produces a little less volume but at a better price. In this sector, the opportunity is enormous as we talk about biofertilizers, biocontrols, etc., and other natural products that dramatically reduce the carbon footprint because you stop using chemicals. The next level up the pyramid is food and beverage ingredients, followed by biomaterials such as fibers, wood, bioplastics, and biocosmetics (antioxidant creams, moisturizers).

At the top of the pyramid are products that are produced in smaller quantities but have a higher economic value per unit, such as biopharmaceuticals, where there is a high degree of biotechnology.

In other words, this pyramid has room for all kinds of activities. Still, some sectors are already developed in the region, such as biofuels and bio-inputs, which are becoming increasingly important. However, there are very few in the rest of the chain of industries. The higher you go up the pyramid, the harder it is to progress because it is more expensive to develop and requires advanced human capital and science and technology infrastructure.

Question 3: What are the constraints in the region's countries in developing and implementing bioeconomic strategies?

Some Latin America and the Caribbean countries have strategies, such as Costa Rica, Colombia, Brazil, Uruguay, and Argentina. You have countries developing them, and finally, you have countries that definitely need a strategy, such as Chile, Peru, Bolivia, Venezuela, Panama, or Mexico; this last country is recently developing one focused on the agricultural sector. There are two types of strategies: national and sectoral; for example, Argentina has a sectoral bioeconomy strategy specifically for agriculture, which has been very well developed regarding its productive potential in the sector.

Then, following the taxonomic definition, there are strategies with and without objectives, where most countries do not have objectives, and it isn't easy to measure impacts and management indicators. A final condition is the financing of these strategies, which most still need to have, i.e., the existence of a state budget to achieve the management objectives established in these strategies. In the case of some countries in the LAC region, Argentina puts resources into its agricultural strategy, Brazil, for example, has no goals but puts resources into its bioeconomy strategy, and Uruguay has a strategy, but I am not aware that it has a budget, Mexico is in the process of constructing a strategy document, which was its first mission, Costa Rica has a strategy but has economic limitations to execute it.

The main constraints could be summarized into three categories: human capital, scientific and technological infrastructure, and, of course, capital
for research. On the first point, I would say that the region has very good scientists, but there are very few of them compared to other countries that invest a lot in R&D. For example, AstraZeneca, a giant pharmaceutical company, has about 3000 scientists doing research in a small European city. In Latin America, it could not be said that there are that many scientists in a single geographical location.

When I talk about human talent in Latin America and the Caribbean, there is human talent, but more is needed for the scale of the bioeconomy sectors. Regarding equipment, biorefineries are only available in some countries, for which a high level of public and private investment is needed. The European Union understands this and has ensured that where biorefineries are available and equipment is idle, researchers and entrepreneurs can use them for research and proof of concept. It has also funded demonstration biorefinery platforms to attract venture capital. This type of infrastructure in the EU is already booked for the next three years.

In the case of Latin America and the Caribbean, certain countries such as Brazil, Argentina, and perhaps Colombia have biorefineries. But even so, there are not enough. So, you have a lot of researchers in laboratories who can produce bioproducts on a small scale. Still, they need to do it in large quantities to prove that it works, that they can scale it up commercially, and that it is important enough for the country. The third missing edge is the need for more resources invested in R&D in the region, and the few resources in place are limited to projects that are not sustainable in the long term.

Question 4. Considering the above, what role do public-private partnerships and academia play in making bioeconomy projects sustainable over time?

These two actors can create favorable conditions for researchers to have the infrastructure to scale up their research. In alliance with the private sector, the latter can take the researchers' advances as a technology transfer mechanism for commercialization through patents or royalties. These mechanisms are possible and happen in many parts of the world, but what is happening in the region is that there are two main limitations: the first is that the political and institutional situation in many countries is chaotic, and the second is that the private sector has had such bad experiences with the public sector in recent decades that there is a lot of suspicion.

There are exceptions, such as Chile and Uruguay, where the synergy between these sectors is quite good. For these public-private partnerships to exist, there must be an initial leadership that must come out of the public sector because they are the ones who generate the country's public policies around projects and programs for the economy that additionally prioritize sects, regions, and industries, among others. In the ideal scenario, triple elite schemes should be managed where public, private, and academic actors are chained together, and the public sector is committed to allocating resources where necessary. Unfortunately, in almost the majority of the LAC region, this leadership does not exist. Very few countries have public policies specific to the bioeconomy, and the governing bodies that manage it have no higher level of implementation. Finally, even if the government says that it is betting on the bioeconomy, it needs to do so in a sustainable or programmatic way, considering that the amount of resources allocated to this issue is insufficient.

Historically, universities have not been linked to the needs of industry. Researchers are measured more by the number of articles they publish. Still, this reality is changing very slowly as universities have recognized the need for more companies with entrepreneurs and are creating business incubators or technology-based start-ups in most countries in the region, such as Argentina, Brazil, and Chile. This initiative has allowed a closer dialogue between entrepreneurs and academia, where researchers can develop proposals to solve specific problems in different economic sectors. As these processes are long-term - in Europe, for example, the process has been in place for 30 years - the results will be visible in the next decade as companies are created from these dialogues.

Question 5. Considering the IDB's actions in the region, what specific bioeconomy projects are being executed, and what have been the main challenges for their implementation?

The BID has many initiatives that are being developed in the region. For example, the Amazon Reinforcement Project is being implemented in several countries, such as Brazil, Colombia, Peru, Ecuador, Bolivia, Venezuela, and Guyana. The bank has created a working space to coordinate its activities in the eight countries. In that context, we work across Amazon at the regional and national levels, with each country involved. For example, in the case of Brazil, they managed a project with us to create a fund to finance investments in Amazon.

What happens is that with this diversity of bioeconomy definitions that exists today, there is a risk of wanting to pass any project as bioeconomy, so many local lines of credit finance various "bioeconomy" activities that can not necessarily be framed in these sectors. There is an external factor that can control the misinterpretation of the appropriations granted, and it is the restrictions placed by international donors. For example, the global program of the Green Climate Fund has its definitions of sectors and activities within which the bioeconomy is framed.

This is also related to the lack of specific public bioeconomic policies in the region's countries; very few have them, and there needs to be a clear definition of what sectors of the bioeconomy are.

The Amazon Strengthening Program's constraints are very few at the moment because they just started a few months ago. This program has several ongoing projects, such as the creation of a network of finance ministers for monitoring natural capital, another to create a network of research institutes for biodiversity, another to strengthen the ancestral knowledge of the Amazon indigenous peoples, gender equity initiatives, trade solutions bioeconomy, among others.

So all the projects mentioned above have challenges and limitations; I can tell you about those related to research and development projects that I am responsible for at the IDB, where the main limitation is the pace of progress because the institutions we have to work with were not designed to work with agility within their administrative processes, which makes them very bureaucratic, i.e. in conclusion, the institutional format is one of the main limitations.

Question 6. What would be the most important recommendation for the bioeconomy sectors and their strategies to be sustainable in the countries of the region?

In the world we live in today, in Latin America, the state's role in the bioeconomy is minimal or non-existent, meaning that any development in these sectors is mainly a private initiative. In other words, in the absence of an active public policy, what we see today as the development of the bioeconomy has come about through the initiative of the private sector, and if there is no state intervention, these initiatives will continue to emerge linearly, with the risk that they will not be implemented sustainably. It would be possible to encourage the emergence of many more bioeconomy companies and create the conditions to certify and ensure that their activities are sustainable if there were an active public policy of support and encouragement.

So, my recommendation for the above is that two key aspects should be taken into account. The first is that these issues must be on the agenda of the president's top priority work, and the second is that there must be a strong government enforcement arm to implement this bioeconomy strategy. The latter is challenging to implement because countries appoint ministers in areas they are not experts in, and there are no specific lines for implementing projects that support the bioeconomy sectors.

Several essential criteria are overlooked regarding sustainability. There are several dimensions of sustainability; for example, when we talk about non-agricultural primary biomass, there are limits to how much can be harvested without affecting the continuity of the species; in many countries, this sustainability by limits still needs to be discovered. Colombia, for example, has an institute that specifically studies endangered species. Then there is the biomass produced by agriculture, which, in many cases, to obtain a better economic return, leads to the conversion of land for crops that are not part of the ecosystem and that have different sustainability impacts; there should also be land use zoning and clear limits on exploitation. Then you have the biomass produced by agriculture, which, in many cases, to get better economic returns, causes land conversion for crops that are not part of the ecosystem and that create different sustainability problems; there should also be land use zoning and clear limits on exploitation. Then we have a third dimension of sustainability, where the US is a good example, where they have laws that define the area, the species, and the quota for the production of biofuels, with penalties for businesses that fail to comply. In the case of waste, the advantage of the bio-economy is the creation of products from this waste, which minimizes its impact.

In conclusion, sustainability is a key issue within the bioeconomy, and countries in Latin America and the Caribbean need to allocate resources to define and apply these criteria.

Photographic evidence of the interview:

10.5. Interview 5

Stockholm Environment Institute
Dra. Monica Trujillo
Research Fellow

Question 1. Based on the expertise of the Institute and the sustainable concept that bioeconomy involves, is this model a good alternative for the development of the LAC region?

It can be an alternative if the foundations of the bio-economy are met. It must be guaranteed that it is a sustainable activity at all stages of the value chain, and it must also be guaranteed that it is a value-added activity that includes science, technology, and innovation; only then, I believe, can it be a very positive model of transformation for our region. Our area has many natural characteristics to benefit from this model. Its endowment of biodiversity and biomass makes it particularly important to benefit from this model. Still, this model must meet sustainability requirements, good governance, incorporating research and development, and existing knowledge**.**
We at the Institute have seen interesting cases compared to other regions; having offices in Asia and Africa, we could implement a bioeconomy vision in all three. Last year, we had a workshop in Bogota with experts from Thailand and Malaysia. We were impressed by Malaysia, which has had an impressive bioeconomy development based on biotechnology in all its components, such as the institutional arrangement, the performance of their companies, the way they incorporate human capital, innovation, etc.; however, this country has not had a breakthrough in the SDGs. This example is important because it highlights the need for sophisticated and patented advances in biotechnology and ensuring sustainability at all stages of the bioeconomy model.

Question 2. In general, what actions or projects is the Institute promoting to help develop the bioeconomy in the region?.

We have a global bioeconomy initiative, an internal project that started in 2018 and will end in 2024. We've completed a series of systematic analyses of all the learning from this period and focused on promoting the bioeconomy at three levels. The first micro level transforms bioresources into bioproducts linked to value chains. The meso level is fundamental because it is the level of public policy and bioeconomy strategies at different national, regional, and local scales. The third level we are working on is the macro level, which consists of macro-regional and global linkages and good cooperation practices, among other things.

Question 3. Among the initiatives that have been in place, which ones have had the greatest impact, and what have been the main constraints to their implementation in the territories?

As I said, we implement these strategies at the three interrelated levels. Among the most relevant, I can mention some exciting cases: at the micro level, we did a case study on the potential of cassava for the bioeconomy in Colombia, using value network analysis, which allowed us to have an umbrella perspective on the potential use of bio-resources, from this study we were able to generate a national program that is being implemented, funded by the Ministry of Science of Colombia. So, this is an excellent example of scaling up public policy at the research case level. Another interesting case is the creation of the Ibero-American Bioeconomy Network, which is at the macro level and is how we connect between countries to exchange experiences and learning.

Regarding the constraints, we have tried to go deeper and used institutional economics to help analyze this. We did this based on the analysis of public policies, the analysis of business organizations, and the development and adoption of technology and innovation. From these levels, we have found that it is not only the technological aspect but also the institutional environment that impacts or limits the development of the bio-economy, and we have found that companies need more inter-institutional coordination. The issue of coordination and the need for clear rules of the game is still very complex, even though there are bioeconomy policies**.**

However, we understand this is a process of institutional adaptation because it is new in the country and is just beginning. Therefore, it is essential to have clear rules for the development of the bioeconomy, where entrepreneurs and producers can take advantage of all the potential, easily connect to technology markets, and facilitate the management of MSMEs throughout Latin America and the Global South, which are critical actors to achieving these transformations.

Question 4. In your experience, how can the sustainability of the bioeconomy projects promoted at the three levels be achieved over time?

There are many issues to discuss in this area; for example, in Colombia, one of the most promoted sectors is bio-inputs, and let us say we all agree that this sector should be encouraged. Still, specific regulations sabotage the development of the industry, such as environmental certifications that hinder its commercialization. In terms of long-term sustainability, we know that the long-term is fundamental. We saw this in the workshop I mentioned, where the Asians showed their plans for 30 or 50 years, which makes it a long-term strategy. For example, in Colombia, despite having already gone through two politically opposing governments, this transformation has been maintained as a strategic action of an executive that shares the vision of developing the country's bioeconomy, with a green growth policy that began in 2018 and from which the pillars for implementing actions on the country's bioeconomy have been developed. Therefore, as a recommendation for countries in the region at the beginning of their development, there must be a long-term policy defining these paths. Then, it will be easier for short-term governments to participate.

This is accompanied by governance, that is, the coordinated action of all the actors concerned (public, private, scientific, and community) to enable these changes in the economic sectors. It is important to remember that different national, departmental, and local governance types exist. Visualizing the coordination spaces in the territories where the bioeconomy should be anchored is important. Perhaps the central axis could be the regional and local governments that bring together the main actors of the territories. This is also where the Institute is active because we see the importance of governance for these transformations. We have created public policy dialogues that design roadmaps for the bioeconomy, and we have done this at the national and sub-national levels to influence local and departmental development plans by including the bioeconomy.

Question 5. What is the role of researchers and research institutes in developing these bio-economy initiatives?

This interface between universities, companies, and research centers is fundamental. Often, there needs to be more coordination and cases where a university supports a company and vice versa. These channels must be fixed because they are costly or need help understanding each other. For example, researchers research theoretical things that are not applied in companies' reality. This is where governments can make it compulsory for these synergies to exist; for example, there should be a standard line of work for the development of SMEs, the strengthening of organizations, and the

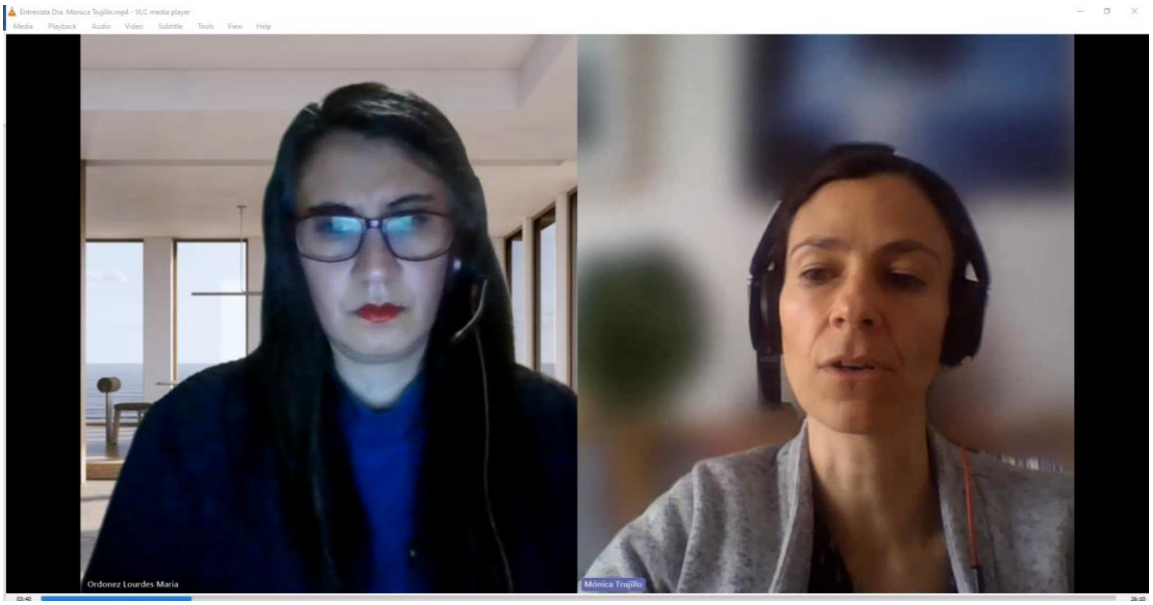
development of market strategies; in other words, with more coherence and guidelines, because one hears many complaints from the private sector about the distance between bioeconomy innovation and academia.

As far as research centers are concerned, our public administrations, which have so much to do and so many needs, in addition to the existing corruption, make the resources available more limited and, therefore, the resources allocated to research and development. On a more specific note, some regions in our countries do not have universities, such as the Amazon region, so in this context, education and research are necessary for development and even less so for the bioeconomy. Therefore, strengthening research institutions and relations with the private sector, companies, and producers is a priority.

Question 6. What are the main sectors of the bioeconomy that will be the driving force behind the country's development?

For the bioeconomy, the Ministry of Science in this government has drawn up a roadmap that prioritizes eight subsectors: functional foods and beverages, biopharmaceuticals, biorefineries, bio-inputs, bioremediation, and nature-based tourism, and the value chains in each of them. Each subsectors has its own lines of action and indicators for achieving its objectives and allocating resources for their implementation.

Photographic evidence of the interview:



10.6. Photographic evidence of primary data collected in two regions in Ecuador

Photo 1: Bamboo producer in Ecuadorian Amazon

Photo 2: Bamboo plants in Amazonia

Photo 3: Bamboo producer organization in Ecuadorian Amazon

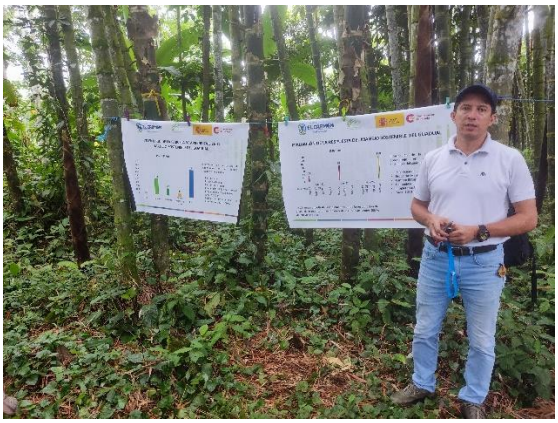


Photo 4: Bamboo producers in Manabi region

Photo 5: Preservation center of bamboo in Tena

Photo 6: Bamboo construction