Hungarian University of Agriculture and Life Science

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

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Thesis of Doctoral (Ph.D.) Dissertation

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1. BACKGROUND AND AIMS

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., 2019; 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 (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; 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; Interamerican Institute for Agriculture Cooperation, 2019; Rodriguez, 2017; Sasson & Malpica, 2018; Schröder et al., 2020).

Given the scarcity of studies determining 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 study's primary author is from Ecuador. The author attempted to highlight the importance of the bioeconomy in LAC through a series of statistical analyses 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.Aims and Objectives

The 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 disparities.

1.2.Research Questions

1. Which are the main bioeconomy sectors in LAC region?
2. How economically important are these sectors in the region?
3. How do bioeconomy sectors are related to sustainable development?

1.3.Research Hypotheses

- ✓ 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.

2. MATERIALS AND METHODOLOGY

2.1. Research design

In summary, Figure 1 shows the graphical interpretation of the research design, which includes the entire framework of the study.

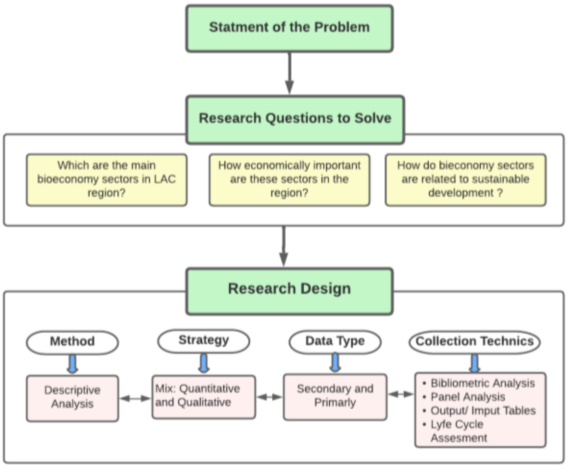


Figure 1. Research Design Chart

Source: Authors own construction

2.2. Research Strategy

Table 1 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.

Table 1. 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	Input 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

2.3.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:

a) *Bibliometric analysis*: For this research topic, the bibliometric data was collected from the scientific database "Web of Science" using keywords related to the research topic.

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 will use 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.

b) *Panel Data Analysis:* 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.

c) *Input/Output Analysis:* 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.

d) *Life Sustainable Cycle Assessment*: The research aims to address 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.

3. RESULTS AND DISCUSSION

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

To answer this first question, we analysed several global and regional documents that helped us understand potential bioeconomy sectors in the LAC region.

Table 2 presents the summarized matrix of documents and the deducted main points 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), to become a significant policy concept in Europe in the early 2000s (European Parliament, 2000).

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 analysed 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., 2017) , 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 2. Summary of the documentary analysis of the bioeconomy sectors identified in the LAC

Type of document	#Doc	Time frame	Institution	Level	Classification of bioeconomy sectors		Summary of sectors
National Bioeconomy Strategies, Bioeconomy Policies, Action Plans, Roadmap for national bioeconomy, Institutional reports, Methodological Guide	10	2012-2024	National Government and related ministries of: Argentina, Costa Rica, Colombia, Brazil, Mexico, Uruguay, Paraguay, Ecuador and Bolivia	Country	50% 50%	No Yes	**General:** Bioeconomy is a paradigm of productive development that cuts **across all sectors of the economy.** **Specific:** 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 fibber production. b) Sectors of the chemical, energy, health, and drug production industries. c) Biodiversity, products and services
Development strategies, Status and Outlook Reports, Programs, Frameworks, regional context and perspectives, and satellite accounts.	7	2019-2024	ECLAC, IICA, CIRAD, MERCOSUR	Regional (Americas)	57% 43%	No Yes	**General:** knowledge-intensive use of biological resources for the production of products and **services across all sectors of the economy.** **Specific:** a) Commodity bioeconomy: products directly derived from the primary bio-based sectors. b) Commodity value-added bioeconomy: products with some degree of processing derived from primary bio-based sectors c) High value-added bioeconomy, manufacturing sectors based on bio-based raw materials
EU Bioeconomy Strategy Progress Report, Safeguarding the US Bioeconomy	2	2020-2022	European Commission, United States Government	Regional (Outside Americas)	50% 50%	No Yes	**All sectors and systems** that rely on biological resources (animals, plants, micro-organisms, derived biomass, organic waste), their functions, and principles. **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.
Global Bioeconomy Report, The Bioeconomy 2030, Policy Brief of Sustainable Bioeconomy and FAO	3	2009-2022	International Advisory Council on Global Bioeconomy, OECD, FAO	Global	67% 33%	No Yes	**General:** use of renewable biomass and efficient bioprocesses to support sustainable production, and the integration of biotechnology knowledge and applications **across sectors.** **Specific:** a) Traditional bioeconomy: agriculture, forestry, fisheries and aquaculture. b) Related processing and service industries: food, paper, textiles, building, construction, chemistry, and biopharma

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 (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 2 summarizes each of these categories

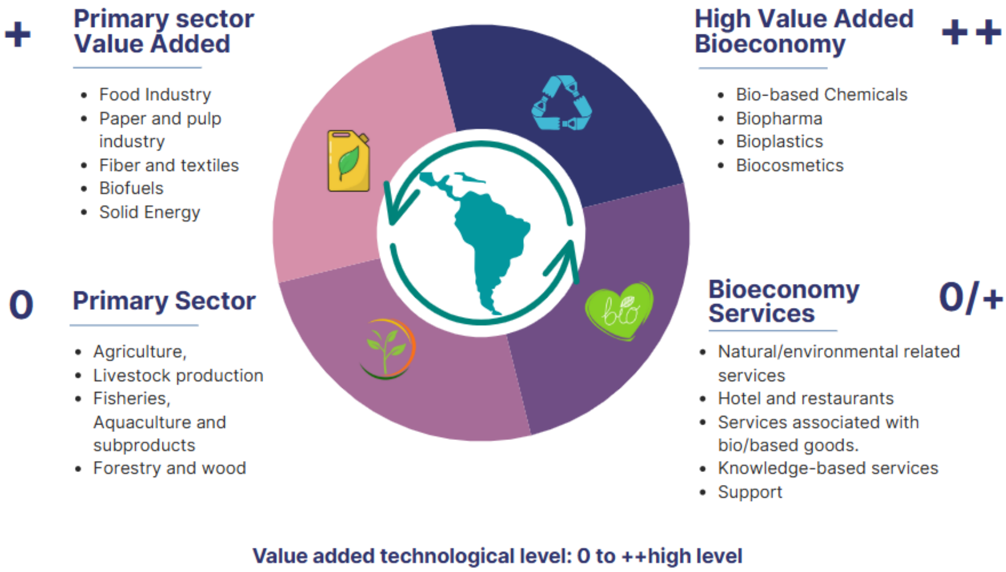
a) Primary sectors: It considers those sectors of the bioeconomy that use and produce 100% biomass, such as agriculture, forestry, aquaculture, and fisheries.

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.

Figure 2. Classification of Bioeconomy sectors for LAC



Source: own construction based on Table 1 data sources and studies of (Rodríguez et al., 2017; Ronzon et al., 2022)

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.

In Figure 3, 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.

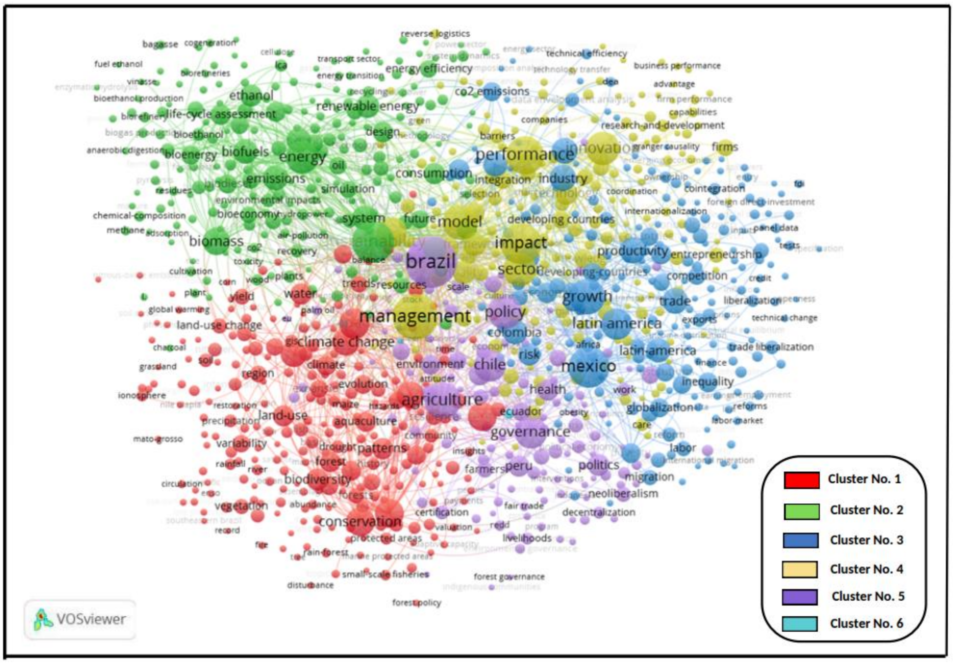


Figure 3. Cluster representation of the corpus analyzed
Source: own construction based on VOSviewer software analysis of the corpus

Table 3 details the bio-economy sectors identified in the region in each cluster and highlights the key concepts of the bioeconomy that are transversal to all the sectors identified.

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 second 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.

Table 3. 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
#Cluster	Keyword related	Link strength	Number of the Cluster	Keyword related	Link strength	#Cluster	Keyword related	Link strength	#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

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 paramount 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. Our findings are consistent with Ordoñez Olivo & Lakner (2023b) bibliometric analysis, which shows 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), It is mentioned that 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 advancement.

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.
For Dr. Anta, the bioeconomy has long existed 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 in other countries such as Ecuador, Colombia, and Costa Rica. There is also an essential distinction between low-tech and high-tech bio-economies. In Latin America and the Caribbean, there are low-tech countries and others with medium-high 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 four essential characteristics. 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 bioeconomy's most historically significant primary value-added subsectors. 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 percentage of biofuels in the mix fuels is 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. Bioethanol accounts for 2/3 of the production and consumption portion while the biodiesel is 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); 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 LAC 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. 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) and 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 fulfills 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 industries 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 (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.

3.2. 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 Economical Commission for Latin America and the Caribbean (2008), those instruments provide a comprehensive conceptual and accounting framework that can be used to create a macroeconomic database suitable for analysing and evaluating macroeconomic performance. We used the Tables of Supply and Use (COU) to explore the importance of the bioeconomy in the region's countries. This is considered one of the most critical 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 4 summarizes the countries selected for the analysis and the years of evaluation. When selecting the countries, it is essential to note that the 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. In line with the descriptive logic statements, 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.

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 analysed in the first stage of the results.

Table 4. 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

3.2.1. Bioeconomy importance in supply

Figure 4 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.

The assumption of the importance of the primary region in the LAC region is also indicated in several studies of (Conroy, Rondinone, De Salvo, & Muñoz, 2024; Gorenstein & Ortiz, 2018b). They highlight 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).

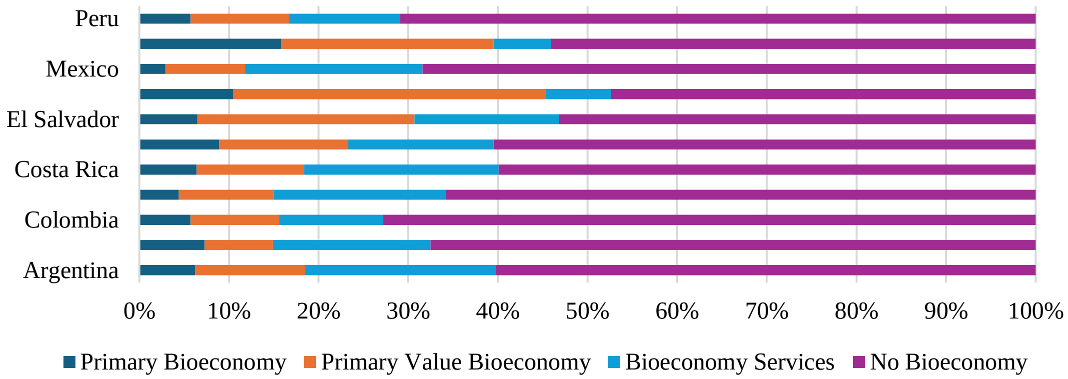


Figure 4. Percentage per bioeconomy category in the domestic production (2018)
Source: own construction

Regarding the share of bioeconomy imports in the countries studied, Figure 5 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.

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 that the share of imports in the primary bioeconomy sector is higher in these countries.

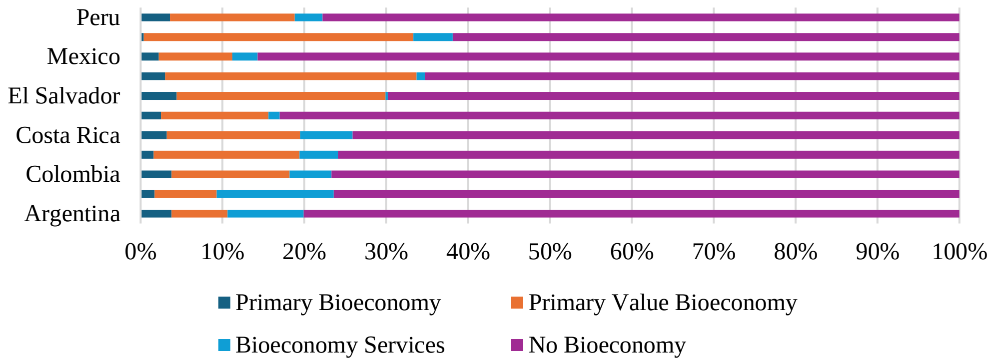


Figure 5. Percentage per bioeconomy category in imports (2018)
Source: own construction

Figure 6 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 analysed. 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 essential to consider that the COVID-19 pandemic occurred during this period. According to the case of Latin America and the Caribbean OECD-FAO (2021), 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 the present study, which shows that primary production and primary value-added have a positive balance in most countries. However, it is essential 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).

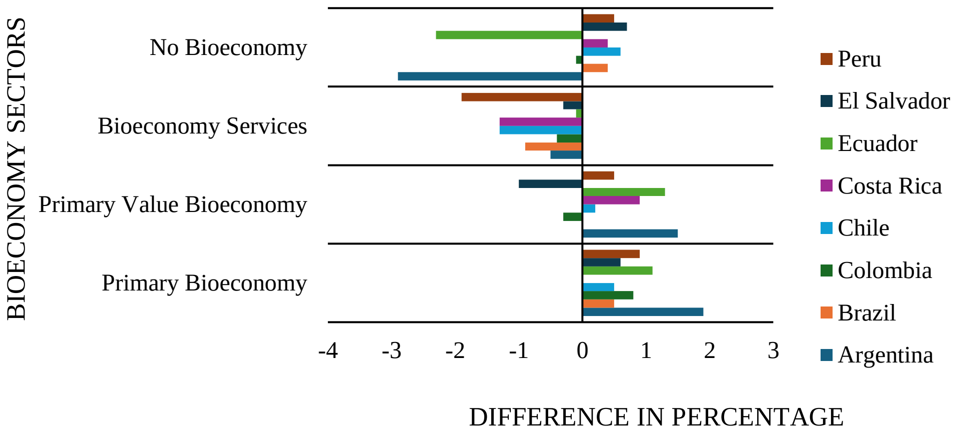


Figure 6. Biannual variation in domestic production of the bioeconomy sectors between 2018 and 2020

Source: own construction

3.2.2. Bioeconomy importance in consumption (demand)

On the consumption (demand) side, intermediate use and total exports of the bioeconomy and non-bioeconomy sectors were analysed. 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 7). 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.

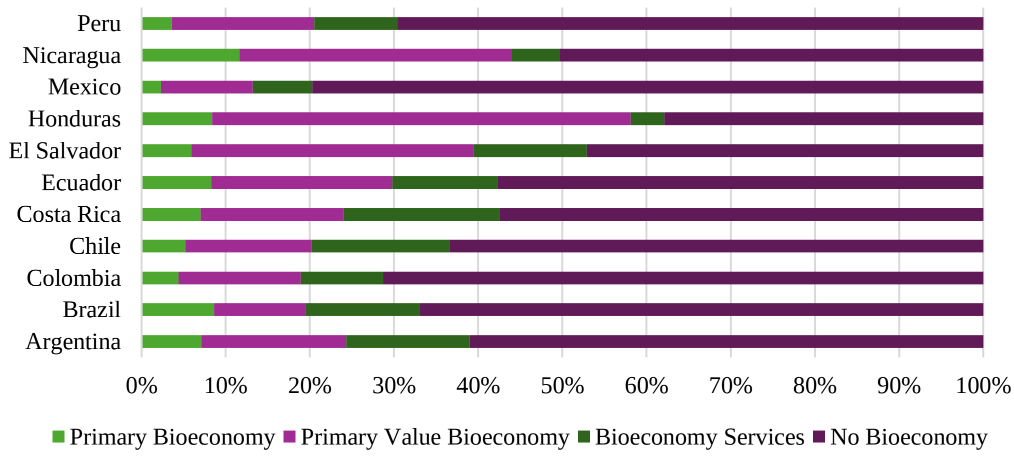


Figure 7. Percentage per bioeconomy category in the intermediate use (2018)
Source: own construction

Figure 8 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).

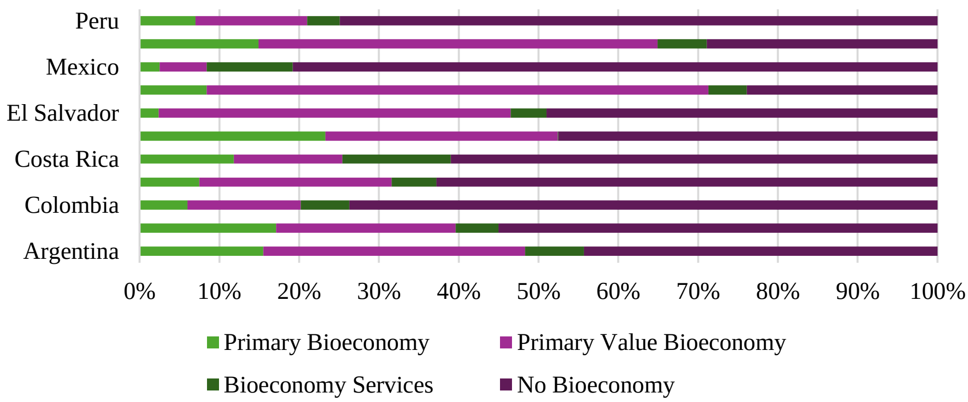


Figure 8. Percentage per bioeconomy category in exports (2018)
Source: own construction

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 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. 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 9 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 growth rate during this period, followed by Chile and Ecuador**.**

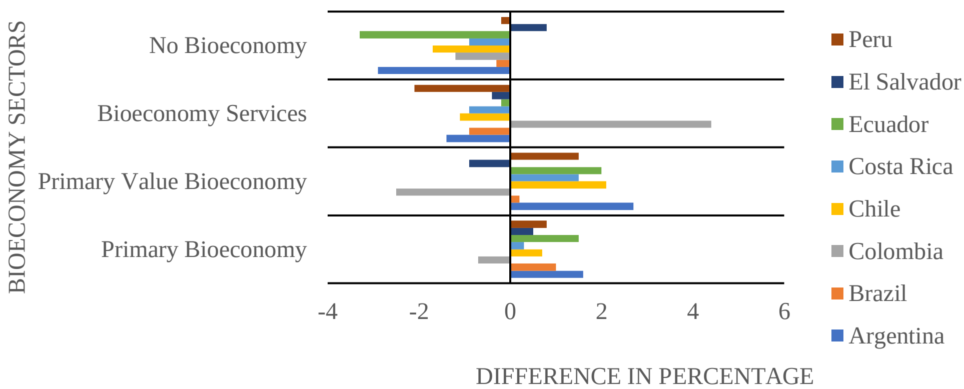


Figure 9. Biannual variation in intermediate use of the bioeconomy sectors between 2018 and 2020

Source: own construction

3.2.3. Bioeconomy importance in gross value added

The position of some countries differs in 2020 from 2018, as not all countries are analysed. 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 (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 bioeconomy were not identified in the national accounts of the studied countries.

In Table 5, 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 5. 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

As mentioned above, an essential macroeconomic indicator of a country is the gross value added to its economy. Table 6 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. T

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.

Table 6. 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

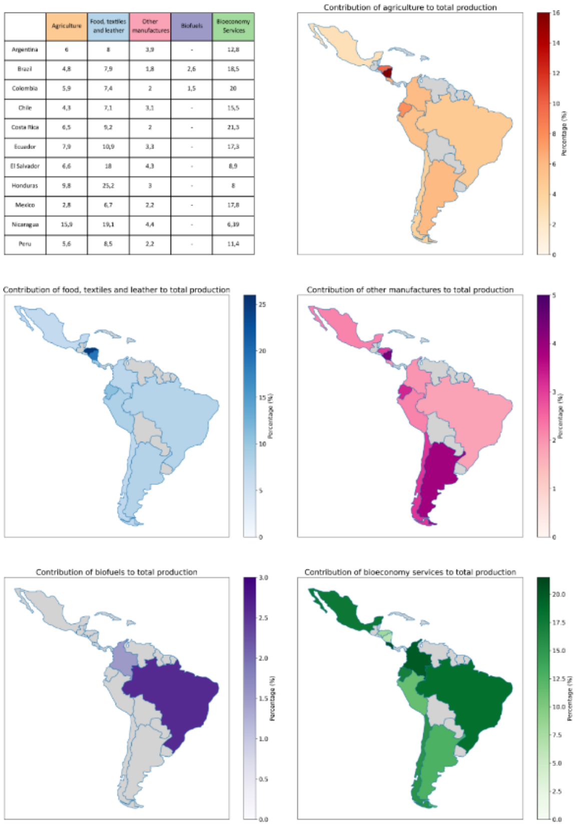
Source: own construction

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

Figure 10 presents geographical maps showing the percentage contribution of each bioeconomy subsector to help interpret the contribution of the different countries' bioeconomy subsectors in 2018. Nicaragua and Honduras are the leaders in agriculture, 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. According to the data obtained from the national accounts of the countries evaluated, only Brazil and Colombia include the different products and activities related to biofuels in the biofuel subsector. Despite being one of the leading biodiesel producers worldwide, Argentina does not include the biofuel subsector's contribution in its national accounts. 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 countries mentioned above 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.

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, fibres 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.



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

3.3. 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.

3.3.1. SDG and bioeconomy as a concept

Using the same bibliometric data mentioned in the first part of the results, Figure 11 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 the total number of articles in the corpus to be determined and then filtered by the relationship of these documents to the SDGs.

Figure 11. 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. The study of Calicioglu, B (2024) 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).

3.3.2. 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.

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 12).

Figure 12. 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 7 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 7. 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.

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.

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

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);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).

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 13 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 principal axes of the bioeconomy principles.
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).

Figure 13. Gender focus in the bioeconomy frameworks of selected LAC countries

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. Table 8 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), 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. For 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. Current results show a direct correlation between R&D investment and the percentage of female researchers.

Table 8. 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

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.

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.

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 greatest 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 the production, harvesting, preservation, and processing of bamboo 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 14).

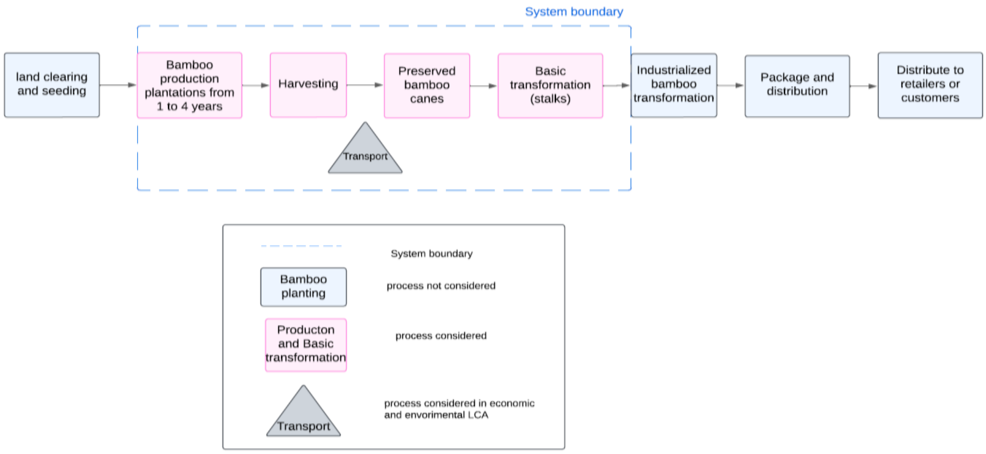


Figure 14. The product life cycle of bamboo production and preservation is considered a system with system boundaries
Source: own construction

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 9). Bamboo production and conservation are considered for the two Ecuadorian regions analysed in this study. Primary data collected for each group identified in the value chain is also considered for the social impact assessment.

Table 9. 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	"Latilla" bamboo manual	1kg
Fertilizers (N, P, K)	0.032KG	"Latilla" 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		
"Latilla" 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.
Source: own construction

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 10).

Table 10. 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

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 culm, the production system is considered, in which the plantation is treated with chemica 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 "latillas" 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 11). The values for the remaining three impact categories are cero, meaning no influence exists.

Table 11. Environmental LCA results for bamboo in two regions of Ecuador

Impact category	Reference unit	Preserve culm (1 kg)	Latilla manual process (1kg)	Latilla 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 "latillas" in the sense that all 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 labour utilized to process the preserved bamboo without any additional machinery or fuel. The climate change category analysed atmospheric emissions converted to CO_2-equivalents. Figure 15 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.

According to our findings and a comparison of data gathered from other timber and non-timber goods studies, emissions from bamboo preserved as a culm and "latilla" 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.

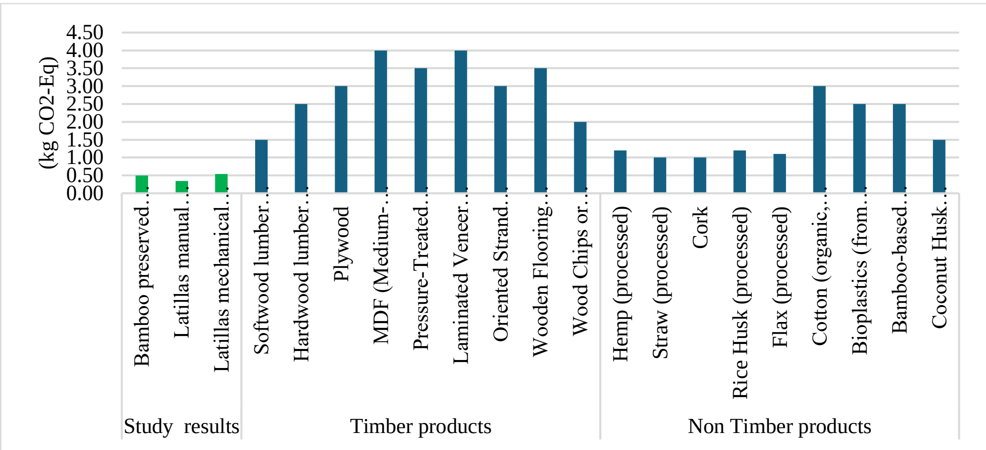


Figure 15. Comparison of Carbon Emissions of study results and Timber and Non-Timber Products

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; Li et al., 2016; Zampori et al., 2013)

Figure 16 shows the main impact contributors regarding kg CO2-Eq emissions of the outputs under study. In the case of preserved culms, the main emission contributors are the chemicals used to preserve the culms, followed by the inorganic fertilizers used in bamboo production. The main contributor for the manual "latilla" is the chemicals used in bamboo preservation and partially the transportation. For the mechanic "latilla", 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.

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 “latilla”, followed by preserved culm, and in the last position the manual latilla. 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 fibres, 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 fibres 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.

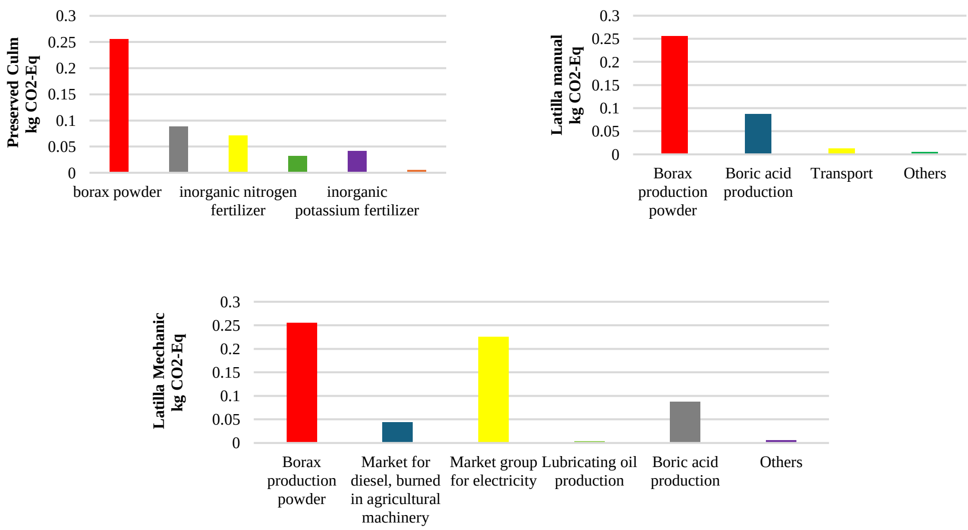


Figure 16. Main impact contributors of Kg CO2-Eq emissions of the studied outputs

Source: own construction

Our finding aligns with the study of Marcel Gauch Paul Vanegas Dolores Sucozhañay et al. (2023), whichevaluates 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. 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 17 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 labour 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 labour rather than mechanical methods. Our findings show that labour 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 culms/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 centre as an organization, the income remains with the farmers.

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.

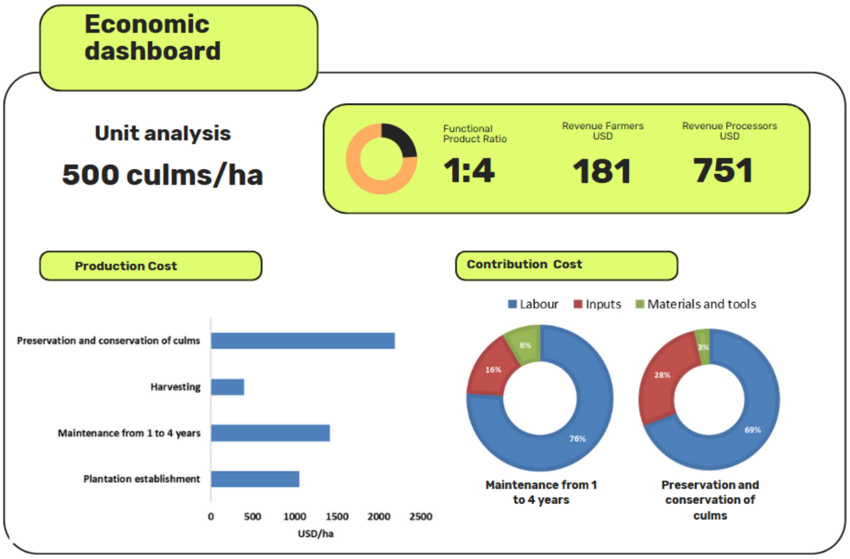


Figure 17. Economic dashboard of the production and preservation of bamboo culms

Source: own construction

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 18 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 culm preservation are the top contributors, followed by harvesting and bamboo production, which rely heavily on human labour for most agricultural activities. The economic features of the bamboo "latilla" 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 18. Percentage of the cost contribution in the preserved bamboo by kg

Source: own construction

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 12 displays the scales and ponderation for each category in the analysis.

Table 12. 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 compared 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
Figure 19 summarizes graphically the analysis of social impact results in Ecuador's two regions. The living conditions of the farmers, the main 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.

However, an attempt has been made to include as much data as possible from each country. This has been done to reflect general data on the situation of the bioeconomy in LAC.

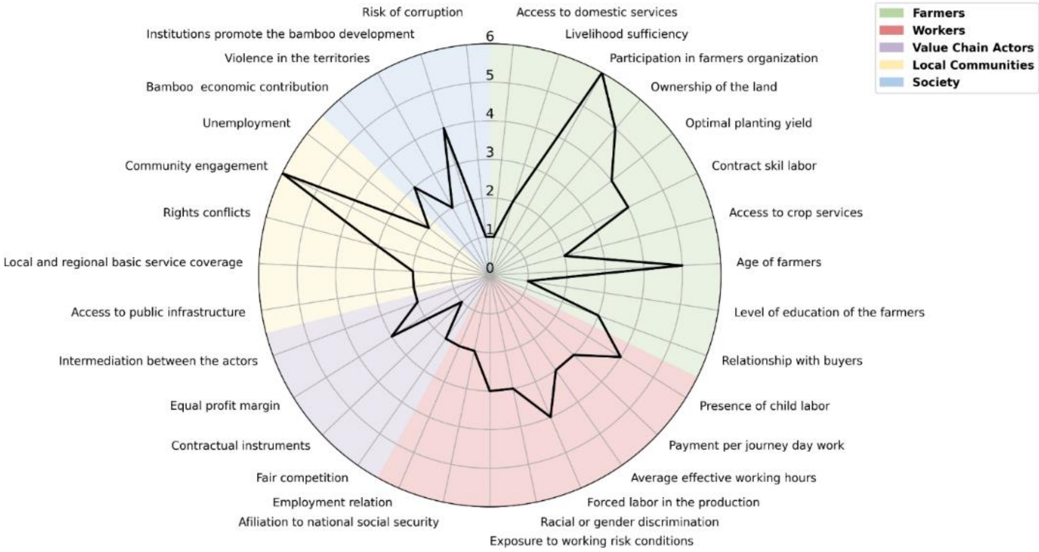


Figure 19. Visual representation of the Social Impact Analysis of Bamboo subproducts
Source: own construction

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.

The same concepts previously mentioned can be seen, and the social impacts have an average weighting of 2.9 points. Regarding the social impact on the bamboo production chain (Zea Escamilla et al., 2018), results show that Ghanaian bamboo bicycle companies' performance did not have a negative socioeconomic impact in most subcategories evaluated in the bamboo production communities. They even made bamboo resource owners aware of the value of bamboo, allowing them to negotiate a reasonable price to contribute to their development.

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 analysing 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 to reflect general data on the situation of the bioeconomy in LAC.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. 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 considering 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 most 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.

4.2. 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 the 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 not possible 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 the environmental, economic, and social impacts of this chain within a specific bioeconomic product in Ecuador using the sustainability assessment methodology.

4.3. 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 analysing 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 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.

4.4. 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.

4.5. 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, 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.

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5. 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 details in the national accounts to assess their financial contribution to GVA.
- The study revealed a significant data gap in historical economic records across the region. Only 11 out of 33 countries were able to 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, CO_2 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 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.

6. LIST OF PUBLICATIONS

- Measuring the sustainability impact of a bioeconomy: Social and Environmental Life Cycle Assessment for Bamboo Poles as a case study from Ecuador
  M.L.Ordoñez, Z Lakner, P Jacome, P.R Izquierdo, F Moreno, C Falconi
  Submitted to Sustainable Development, Wiley, 2025

- Examining the nexus between productivity growth, circular bioeconomy, and climate change: A Bibliometric Analysis
  ML Ordoñez, E Luzón, R Krisztián
  Accepted for publication in Agrosystems, Geosciences & Environment, Wiley, 2025
  DOI: http://doi/10.1002/agg2.70085

- Gender differences in research fields of bioeconomy and rural development-based on sustainable systems in Latin America and Africa regions
  MLO Olivo, RA Oluwakemi, Z Lakner, T Farkas
  PlOS ONE, 2024
  DOI: DOI: 10.1371/journal.pone.0308713

- A Bibliometric Analysis of Women's Empowerment Studies Post Sustainable Development Goal Adoption Periods (2015–2022).
  OR Adeleye, MLO Olivo, T Farkas
  Sustainability, MPDI 2023
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- Food Security and Biofuels in Latin America and the Caribbean Region: A Data Panel Analysis on Eight Countries.
  M.L. Ordoñez, Lakner. Zoltan
  Energies, MDPI, 2023
  DOI: DOI: 10.3390/en16237799

- Current scenarios of circular economy in Brazil and Ecuador: review article
  M.L. Ordoñez, Martins, Caroline
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  DOI: DOI: 10.33568/rbs.4685

- Shaping the Knowledge Base of Bioeconomy Sectors Development in Latin American and Caribbean Countries: A Bibliometric Analysis.
  M.L. Ordoñez, Lakner. Zoltan
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  DOI: DOI: 10.3390/su15065158

- Bioeconomy as a sustainable development model: study case of Latin America and the Caribbean region
  M.L. Ordoñez
  XXIX. Youth Scientific Forum: Conference volume, 2023
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