sustainability

Review

Shaping the Knowledge Base of Bioeconomy Sectors Development in Latin American and Caribbean Countries: A Bibliometric Analysis

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Abstract: Academic research on bioeconomy sectors in Latin American and Caribbean countries has developed exponentially over the last few years. Based on the Web of Science (WOS) database and statistical analysis of more than 18.9 thousand documents, the current article offers a bibliometric analysis of these datasets. The main bioeconomy sector identified in the results was biofuel production and all the background terms related to the primary processes of bioenergy. The other segments of the bioeconomy in the Latin America and Caribbean (LAC) region have not yet been studied with the same relevance as biofuels. Since 2008, researchers from Latin American and Caribbean countries have participated significantly in the scientific production of the field studied. However, the most relevant scientific journals belong to European countries or the United States. Journals from Latin American and Caribbean countries have very low representation, although the search topics are directly related to this region. Based on the co-occurrence of keywords, eight clusters with different levels of importance can be distinguished: (1) agriculture; (2) climate change; (3) biodiversity; (4) bioremediation; (5) bioenergy; (6) biofuels; (7) energy efficiency; and (8) bioeconomy. The above results highlight the significant research gap between biofuels and other types of bioeconomy sectors in the region. This is despite the immense biodiversity potential of the LAC countries, which can generate innovative products with bioeconomic added value that can stimulate scientific research in the sustainable bioeconomy.

Keywords: bioeconomy; LAC region; bibliometric analysis; biofuels; sustainability; R software

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1. Introduction

According to the Global Bioeconomy Summit in 2018, bioeconomy refers to "the production, utilization, and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes, and services across all economic sectors aiming towards a sustainable economy [1]".

One of the main goals of the bioeconomy is the reduction of non-renewable fossil energy use and its replacement by renewable resources [2–4]. Nevertheless, other objectives include linking all economic and industrial sectors that use biological resources and process them to produce food, feed, bio-based products, and services [5] or, in some cases, the optimization of the life cycle of the products and the creation of secondary markets for bio-based products [6].

According to Linser, S. (2020), many bioeconomy strategies are relevant to several SDGs (14 out of 17), making it a sustainable pathway to achieving the UN Sustainable Development Goals [7,8]. Furthermore, bioeconomy can be seen as a response to at least four emerging and converging global challenges: (a) growing global population; (b) increasing global demand for biomass (at least 60% above current rates), exacerbating the scarcity of natural resources; (c) growing evidence that the era of oil and cheap energy is coming to an end; and (d) concerns about climate change [4,8]. In summary, the relationship of the bioeconomy to SDGs and the global challenges can be grouped into three dimensions: socio-economic, environmental, industrial, and economic drivers [9,10].

These drivers are directly related to the sustainability aspects of the bioeconomy, towards which progress can be made when certain conditions are met [11]: "(i) sustainability of the resource base; (ii) sustainability of processes and products; and (iii) circular processes of material flows" [12]. In addition, the environmental and production components of bioeconomy development approaches need to be closely linked to how bio-resources are supplied, produced, and consumed [13].

The potential of the bioeconomy needs to be steered in the right direction to ensure that it works for people, food and nutrition security, and sustainable economic growth while preventing climate change and not harming the environment [14,15]. Therefore, some countries around the world contributed with significant knowledge, policy, and institutional efforts to develop bioeconomy strategies.

According to the German Bioeconomy Council [1], the bioeconomy has gained strength worldwide and is a certainty in many developed countries such as Germany, France, Finland, the Netherlands, Russia, and Japan [16]. At the beginning of 2018, nearly fifty countries have included a defined bioeconomy policy or strategy in their development plans or in their sub-regional procedures.

Nowadays, the bioeconomy has also been adopted by many low and middle-income countries as a new development concept and as part of their commitments to the Paris Climate Agreement [17]. In the case of Latin America and the Caribbean, a sustainable bioeconomy could open up new opportunities for economic development and industrialization and support economic and social goals [8,18].

Latin American and Caribbean countries have the most significant global endowments of natural capital because of their great diversity and natural resources, which are primarily the basis of their economies [19]. The region possesses the highest biomass production related to the availability of soil, water, and land [20]. Due to its high level of biodiversity, it tends to make a more significant contribution to the quality of life of people on average than other regions of the world [21,22].

In this context, the bioeconomy in Latin America and Caribbean countries has two main sets of objectives. On a global level, the region plays a critical role in contributing to global food, fiber, and energy balances, while improving environmental sustainability. Within the region's boundaries, the bioeconomy is a new source of opportunities for equitable growth through improved agricultural and biomass production [23,24].

Considering the comparative advantages and experiences in the countries of the Latin America and Caribbean region, Trigo et al. identified six distinct pathways that offer a holistic approach to the bioeconomy initiatives in the region. These six pathways include "(a) biodiversity resources exploitation; (b) eco intensification of agriculture, (c) biotechnology applications; (d) bio-refineries and bio-products, (e) value chain efficiency improvement; and (f) ecosystem services" [23].

The aim of this paper is to present a bibliometric analysis of the bioeconomy sectors developed in Latin American and Caribbean countries in recent years, based on the authors' evaluation criteria to determine the final products obtained from biomass processing, which in this study are biofuels, bioenergy, biotextiles, biocosmetics, and biopharmaceuticals. The countries considered in the analysis are those that have relevant bioeconomic approaches according to the revised bibliography (in the case of South America, Brazil, Argentina, Uruguay, Colombia, and Chile and in the case of the Caribbean, Mexico, Cuba, and Costa Rica).

2. Materials and Methods

In the present research, we applied the traditional bibliometric analysis. Figure 1 presents the workflow of the essential steps used in the dataset.

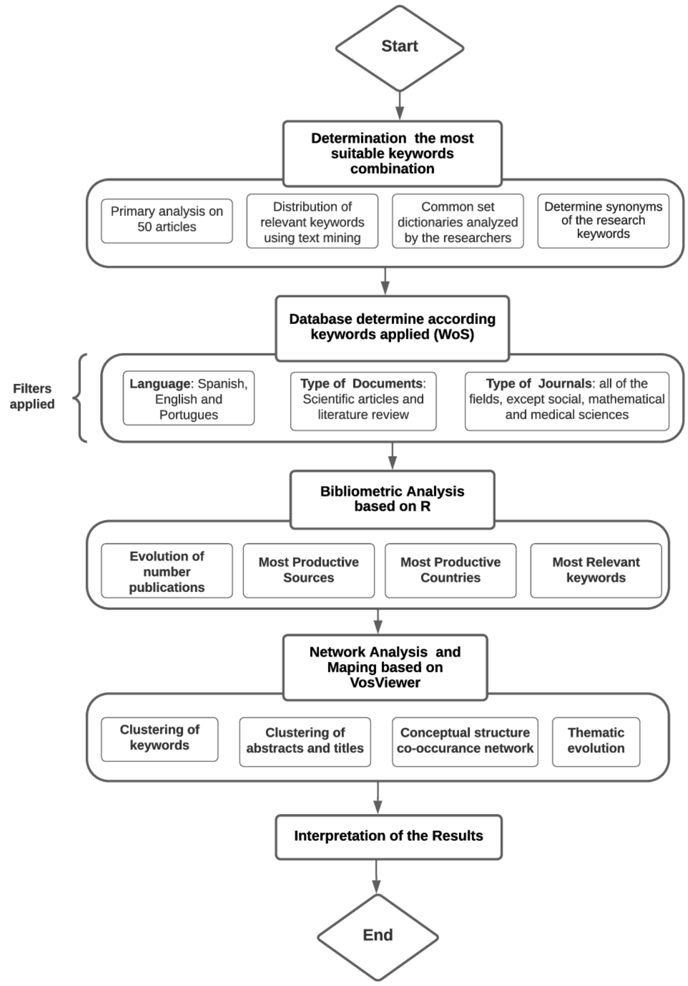

Figure 1. Flowchart of the research.

2.1. Data Sources and Collection

The bibliometric research has been carried out on the basis of the Web of Science database. A total of 18,971 documents were the subject of the analysis, and the time span of the publications under consideration was between 1977 and 2021.

To determine the most suitable keyword combination, the authors applied the parti pris concept [25]. In the first phase, we downloaded 50 articles using the simplest keyword combinations and then analyzed the distribution of relevant keywords using text mining methods. Subsequently, we set up a preliminary dictionary of potential keywords, which was carried out separately by each of the two co-authors. In the second phase, we determined the standard set of dictionaries and analyses the proportion of such words in the lexicon of each of the authors. At the end of this phase, we applied "Roget's Thesaurus" [26] to determine the potential synonyms of the research terms. After all these stages, we consider that we have achieved the type of keyword combination, which proved to be quite solid and robust, and which includes the main sectors of the bioeconomy developed in Latin American and Caribbean countries, with relevant bioeconomic initiatives related to the final products obtained from biomass.

The present research had the most reliable and interpretable results with the following keyword combination: TS = ((("bioet*") OR ("bioenergy*") OR ("biodies*") OR ("biogas*") OR ("short rotation crop*") OR ("biofuel") OR ("energytree*") OR ("energygaps") OR ("energyplantation") OR ("energy plantation") OR ("energy forest*") OR ("biomass*") OR ("biocosmetic*") OR ("bio-cosmetic*") OR ("biopharma*") OR ("biofiber*") OR ("biofibrer*")) AND ((("Brazil*") OR ("Brasil*")) OR ("Argentin*") OR ("Chile*") OR ("Uruguay*") OR ("Mexic*") OR ("Cuba*") OR ("Colombia*") OR ("Costa Rica*"))).

Given the large size of the corpus to be analyzed, it was decided to apply structural breaks according to the number of publications that had changed over time for the bioeconomy sectors developed in Latin America and the Caribbean. The structural breaks in the time series were determined using the algorithms of the Strucchange R-package [27], the specialist estimation Z.L, and the econometric time-series analysis carried out by the econometric software Gretl (ver. 2022.c-64) [28]. On this basis, four periods were identified: 2000, 2001, and 2007, 2008 and 2014, and from 2015 to 2021. The interpretation and justification of these four periods are based on the milestone years in various historical datasets that have been researched for this purpose (Table 1), in addition to the results of the mathematical and statistical methods carried out using R and Gretl software. The mentioned sources provide statistical data regarding the established breakpoints and the period variance (Appendix A, Figures A1–A3).

Table 1. Historical records of three different variables which support the breakpoints established in the study.

Milestones Years	Public Investment in Bioenergy Sector (Million Dollars)	Renewable Share (Modern Renewables) in Final Energy Consumption (Percentage)	Primary Energy Supply from Clean Renewable Sources in LAC and the Caribbean (Thousands of Barrels of Oil Equivalent)
Up to 2000	13.24	6.86	431,710.1
2001–2007	126.52	7.48	551,923.1
2008–2014	7682	9.04	650,628.1
2015–2021	4046.48	10.88	740,115.5

Prior to the year 2000, the bioeconomy sectors in the world were taking their first steps towards development, in particular in regions such as Latin America and the Caribbean. According to the International Renewable Agency [29], public investment in the bioenergy sector did not exceed 13.6 million. This indicator is also related to the consumption of final energy from renewable sources, which was 0.62% lower than the next established breakpoint [30,31]. Since 2001, there has been evidence of significant changes in the level of consumption of biofuels at the global level and in the clean supply of renewable sources in the countries of Latin America and the Caribbean [32,33]. Finally, a significant increase in bioeconomy sectors worldwide occurred between 2008 and 2014; this could also be directly related to the policies and strategies proposed in EEUU, Canada, Germany, Austria, and Finland [34,35].

2.2. Data Analysis

In order to analyze and visualize the corpus data, a detailed bibliometric analysis was carried out using the Bibliometrix R-package. This program provides a wide variety of statistical functions (linear and non-linear modeling, classical statistical tests, time-series analysis, classification, clustering) and graphical techniques [36,37]. To complement the statistical analysis of the research, we also used the VOSviewer 1.6.18 software [38–40]. Table 2 shows the statistical indicators applied in the present research.

It is important to emphasize that the data obtained are the result of a global search for scientific production in the periods indicated and follow the keywords defined as the most appropriate for this research.

Table 2. Software tools applied to the corpus for statistical analysis.

Type of Software	Type of Statistical Analysis
Gretl econometric software	• Econometric analysis of the structural break points of the main dataset base based on the article's years of production
Bibliometric (biblioshiny)	• Yearly academic production. • Most relevant sources in the field of Bioeconomy in relation to the Latin America and Caribbean region. • Evolution of authors' keywords in the bioeconomy literature [41].
VOSviewer	• Co-occurrence of different keywords and expressions applying a combination of clusters in the four periods to analyze [42].

2.3. Limitations

During the keyword search process, after following the guidelines in Figure 1, we noted that we had achieved the type of keyword combinations that were robust and firm enough to achieve the results to be displayed. The previous statement indicates that subtracting or adding a less relevant keyword could not considerably influence the number of results.

It is important to note that, as described in the methodology, the definition of the search terms was based on the previous review of 50 scientific articles that showed a priority focus on one of the most technologically and economically developed sectors in the region, i.e., biofuels. A few initiatives related to other biomass-derived products could also be considered relevant sectors. Therefore, only those initiatives identified in the keyword search were included.

However, as authors, we are aware that our research only covers some sectors currently considered part of the bioeconomy, which may have been further developed and researched. Similarly, we know this research only covers some relevant articles on the subject, as it is extensive and has grown exponentially in recent years.

3. Results

3.1. General Characteristics of the Corpus

The corpus of this research contains 18,971 documents. It represents a global search of scientific production in the four periods indicated, according to the keywords used. The published documents are analyzed according to the authors, the institutions linked to the corresponding countries, and the average number of citations of the articles at the world level [43]. In this set of data, the average number of citations per article per year is relatively high (2.068).

Figure 2 shows the global scientific publications between 1977 and 2021 in relation to the bioeconomy sectors developed in the LAC region. The high level of interest is reflected between the years 2000 and 2021, with 91% of the scientific production concentrated within the evaluation period of 44 years. This interest is also directly related to the investments made in LAC countries in the final products derived from biomass processing, such as biofuels and others. According to the International Renewable Energy Agency [41], there has been an 11 percentage point increase in investment in renewable energy in LAC since 2004, compared to a 6 percentage point increase worldwide. Countries such as Brazil, Argentina, Mexico, and Chile have joined the list of the world's top 10 renewable energy markets.

Table 3 shows an analysis of the cumulative share of publications in the corpus, based on the global search of scientific output in the analyzed period. This cumulative share is a measure constructed from the publication frequency of the corresponding authors (intra- and inter-CCP country) during the four periods analyzed. In the early years of bioeconomy development in LAC, it was dominated by the United States and four representative South

American countries: Brazil, Mexico, Argentina, and Chile. The European countries of Germany and the United Kingdom appear in sixth and seventh place among the producing countries in the following period analyzed. From 2008 onwards, there is a rapid increase in the participation of other South American countries, such as Colombia and Cuba, and the appearance of major Asian countries, such as China and India. In recent years, the share of Latin American countries has grown even faster: five countries are among the 20 most productive.

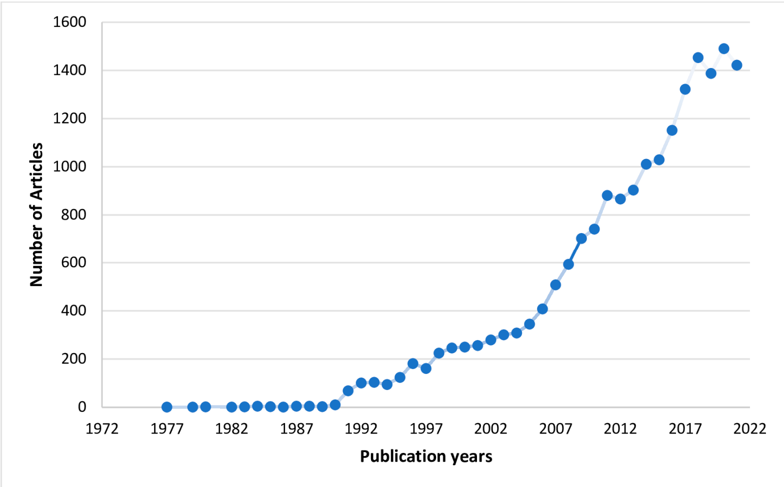

Figure 2. Scientific publications between 1977 and 2021 related to bioeconomy sectors developed in Latin America and Caribbean region.

Table 3. The cumulative share of the top 15 countries in publications with corresponding authors' contribution to bioeconomy sectors (countries indicated by 3-digit ISO codes).

1977–2000		2001–2007		2008–2014		2015–2021	
Country	**Cum. Share of Publications (%)**	**Country**	**Cum. Share of Publications (%)**	**Country**	**Cum. Share of Publications (%)**	**Country**	**Cum. Share of Publications (%)**
USA	0.28	USA	0.24	BRA	0.37	BRA	0.42
BRA	0.44	BRA	0.46	USA	0.52	MEX	0.54
MEX	0.57	MEX	0.57	MEX	0.61	USA	0.63
ARG	0.68	ARG	0.68	ARG	0.70	ARG	0.69
CHL	0.74	CHL	0.74	CHL	0.76	CHL	0.74
DEU	0.78	DEU	0.79	COL	0.79	COL	0.79
GBR	0.81	GBR	0.80	DEU	0.81	DEU	0.81
FRA	0.84	CAN	0.82	GBR	0.82	CHN	0.83
CAN	0.85	CUB	0.83	ESP	0.84	GBR	0.84
CRI	0.86	FRA	0.85	FRA	0.85	ESP	0.86
COL	0.88	ESP	0.86	CHN	0.87	CRI	0.87
NLD	0.89	COL	0.88	CAN	0.88	IND	0.88
ESP	0.90	AUT	0.89	NTD	0.89	NTD	0.89
IND	0.91	CRI	0.90	IND	0.90	URY	0.90
AUT	0.92	ITA	0.90	CRI	0.91	CUB	0.91

The above data are consistent with González, C. et al., (2016) findings. They show that developing countries are narrowing their science gap, with R&D investment and scientific impact growing at more than twice the rate of the developed world. However, among the countries assessed, the scientific output and impact are relative to their level of investment and the resources available to them and are not necessarily being carried out in an efficient manner [44].

Figure 3 shows the temporal changes during the four implementation periods of the bioeconomy sectors in Latin America and the Caribbean. It is based on the frequency of publications per country over time and interpreted in the territorial maps. In all the periods analyzed, Brazil and the United States were in the lead in terms of scientific production, followed by Central and South American countries such as Mexico and Argentina. The main difference lies in the frequency fluctuation of publications (expressed as a percentage on the map) among these key countries. Another interesting process observed in the last ten years is the active role of countries such as Brazil, which is the leading producer, accounting for almost 42% of the total number of publications, followed by the United States (17%), Mexico (13%), Argentina (9%), and Chile (7%). All these data highlight the global nature of bioeconomy sectors and the importance of Latin American countries in scientific production on this subject.

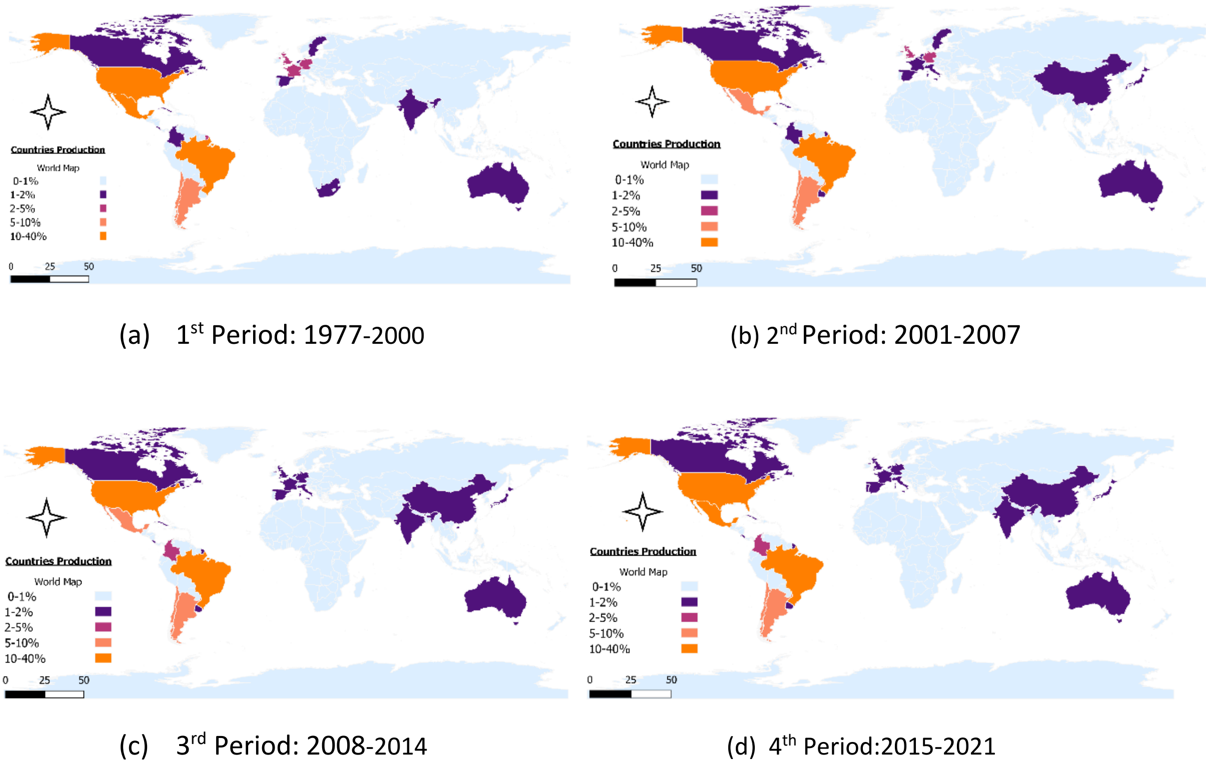

Figure 3. Temporal changes in the spatial distribution of bioeconomy-related publications measured by countries' production percentage (Map created in R with base map courtesy of OpenStreetMap).

Based on the number of scientific articles published per journal, Table 4 shows the most relevant academic journals. For the purposes of this analysis, the descendant rank of the journal and the country of origin are taken into account accordingly. It is interesting to note that developed countries account for a higher proportion of top scientific research articles and have a robust research impact in this field. European countries such as the Netherlands, the United Kingdom, and Germany, together with the United States, are in the top 10 of the journal spectrums. Contrary to the previous analysis of country production, in the case of top journals, only a few belong to South American countries, such as Brazil, with the highest participation, followed by Chile and Costa Rica.

Table 4. The 14 most relevant academic journals in the 4 periods evaluated in the field of bioeconomy sectors in the Latin America and Caribbean region.

1977–2000		2001–2007		2008–2014		2015–2021	
Name Journal	**Country**	**Name Journal**	**Country**	**Name Journal**	**Country**	**Name Journal**	**Country**
Journal of Geophysical Research-Atmospheres	USA	Forest Ecology and Management	NLD	Forest Ecology and Management	NLD	Journal of Cleaner Production	UK
Hydrobiologia	NLD	Journal of Geophysical Research-Atmospheres	USA	Atmospheric Chemistry and Physics	DEU	Forest Ecology and Management	NLD
Marine Ecology Progress Series	DEU	Hydrobiologia	NLD	Revista Brasileira de Ciencia do Solo	BRA	Plos One	USA
Revista de Biologia Tropical	CRI	Marine Ecology Progress Series	DEU	Biomass and Bioenergy	UK	Renewable and Sustainable Energy Reviews	UK
Forest Ecology and Management	NLD	Revista de Biologia Tropical	CRI	Energy Policy	UK	Science of the Total Environment	NLD
Pesquisa Agropecuaria Brasileira	BRA	Revista Brasileira de Ciencia do Solo	BRA	Plos One	USA	Biomass and Bioenergy	UK
Biotropica	USA	Atmospheric Environment	UK	Revista de Biologia Tropical	CRI	Industrial Crops and Products	NLD
Oecologia	USA	Ecological Applications	USA	Renewable and Sustainable Energy Reviews	UK	Renewable Energy	UK
Revista Chilena de Historia Natural	CHL	Biotropica	USA	Hydrobiologia	NLD	Remote Sensing	USA
Plant And Soil	NDL	Ecological Modeling	NLD	Brazilian Journal of Biology	BRA	Sustainability	CHE
Journal of Range Management	USA	Plant And Soil	NLD	Latin American Journal of Aquatic Research	CHI	Environmental Science and Pollution Research	DEU
Journal of Tropical Ecology	UK	Field Crops Research	NLD	Atmospheric Environment	UK	Forests	CHE
Field Crops Research	NDL	Journal ff Arid Environments	USA	Pesquisa Agropecuaria Brasileira	BRA	Revista de Biologia Tropical	CRI
Soil Biology and Biochemistry	UK	Global Change Biology	UK	Plant And Soil	NLD	Fuel	NLD

This phenomenon can also be explained in terms of the gross domestic expenditure on R&D that countries invest on an annual basis. In 2018, North America and Western Europe invested around 2.5% of their GDP, while Latin America and the Caribbean invested only 0.7%, according to the Unesco Global R&D Investment Report [45]. If we analyze the countries of Latin America and the Caribbean, Brazil is the country that invests the most, with 1.7% of GDP, and is ranked 9th among the top 10 countries in the world for investing in R&D. Several studies show that there is a strong positive correlation between R&D expenditure and scientific production [46,47]. Melo et al. conclude that countries that spend more on R&D have more universities and ISI-indexed journals and produce a significant volume of research papers.

3.2. Analysis of Keywords and Co-Keywords

Figure 4 shows the frequency of the different keywords over time. Aspects related to "biomass" and its different variants and concepts such as "biodiversity" reflect permanent growth. Terms related to climate change factors, such as land use change, deforestation, and degradation, are another group of terms identified in the corpus. Keywords associated with renewable fuels reflect their growth in importance over the last 15 years. Finally, terms such as "sustainability" and "life cycle assessment" show less growth. However, these latter terms have a direct cross-cutting relationship with most of the topics analyzed and are fundamental concepts for compliance with Sustainable Development Goals.

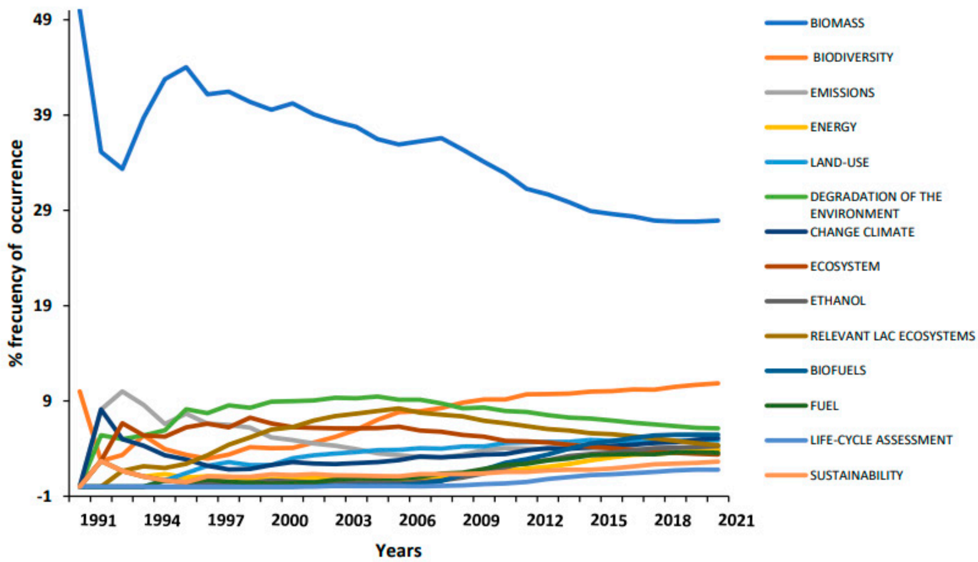

Figure 4. Frequency of occurrences of keywords on the corpus "−1".

The analysis of the second body is based on the frequency of the relevant words used by the authors during the period described (Figure 5). These words are directly related to the bioeconomy sectors developed in Latin America and the Caribbean. Some keywords appear exponentially as "biofuels" or "biogas", which shows the growing sensitivity of the academic environment towards renewable energy as the most important bioeconomy sector that has been established in this region.

For the purposes of this study, "biomass production" includes other sectors of the bioeconomy (e.g., biocosmetics, biopharmaceuticals) which do not have the same relevance and scientific production compared with biofuels.

Interestingly, terms such as "bioethics" appear with greater frequency from 2006 to 2016 as part of the glossary used by the authors, demonstrating the importance of including moral principles and values in all scientific research. It emphasizes the balance to be struck between ethical principles, technological possibilities, and several conflicting human needs, such as producing food and, in particular, renewable energy based on first-generation biofuels [48].

Finally, the term "REDD" appears with minority participation, although it is a relevant concept for the sustainable management of ecosystems, especially for developing countries such as those in the Latin America and Caribbean region.

3.3. Clustering of Research Topics Based on Co-Occurrence of Keywords

As mentioned in the previous sections, there have been significant changes in the research area in recent years. For this reason, a co-occurrence-based analysis was carried out in the VOSviewer software between the years 2015 and 2020. Figure 6 shows a summary of the results obtained.

The analysis performed makes it possible to differentiate eight-dimensional coordinate clusters. These clusters are interconnected and have different levels of importance according to the number of items they contain.

The largest cluster in terms of word number includes Agriculture and Soil Research (No. 1, shown by red color). In this cluster, soil management and soil properties are key factors for agriculture productivity. The same applies to biomass production systems, which deal with the use of agricultural land for bioenergy production. In terms of the relationship between sustainability and agriculture, the cluster contains important keywords such as conservative, sustainable, and functional diversity.

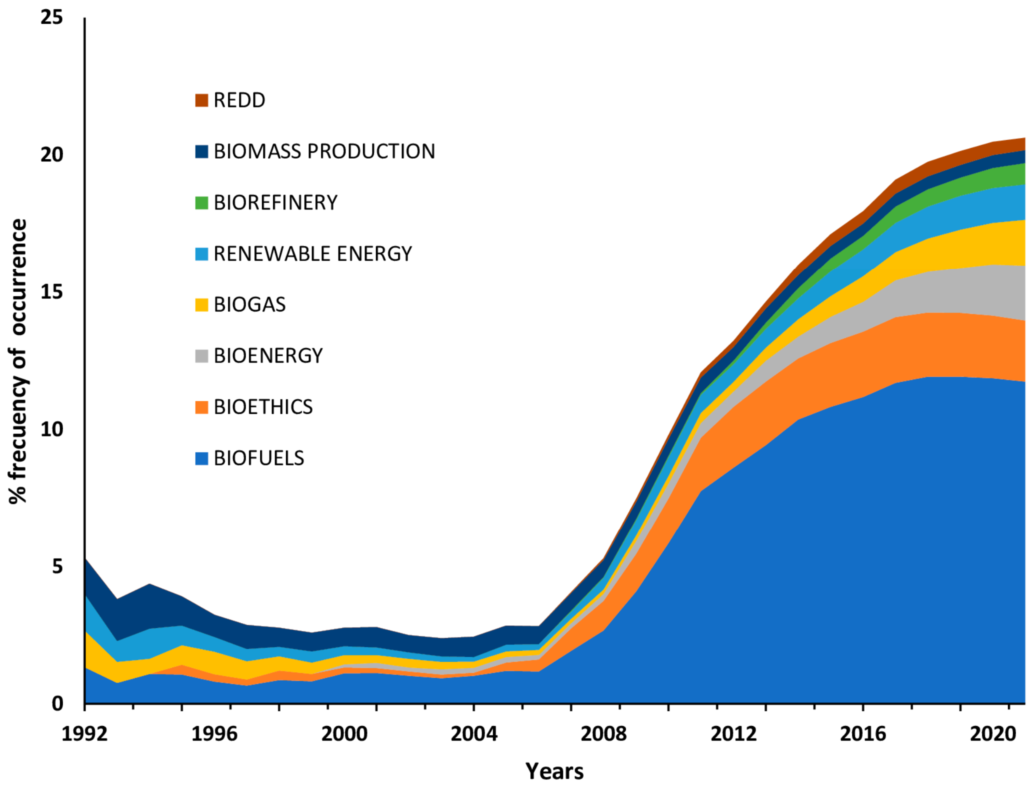

Figure 5. Frequency of occurrences of specific authors' keywords relevant to the corpus " −2".

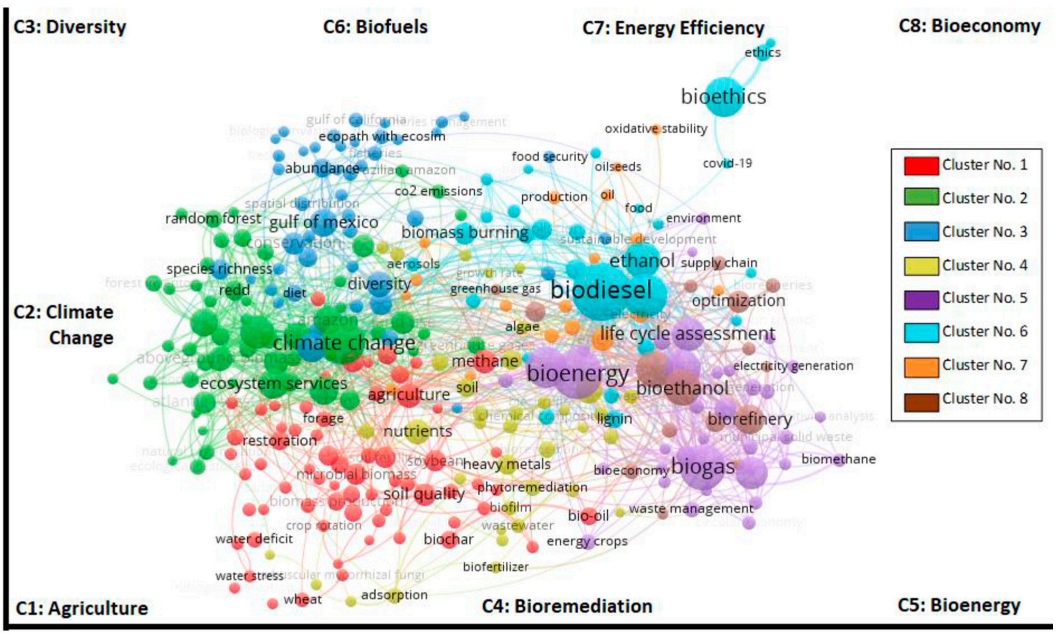

Figure 6. Key clusters of bioeconomy sectors developed in Latin America and the Caribbean.

The second cluster, indicated by green color (No. 2) consists of 37 items, most of which are related to factors that affect climate change. This cluster highlights the relationship between biomass production strategies, particularly in the context of bioenergy and the impact of climate change.

The third cluster (No. 3, colored blue) deals with diversity and conservation aspects, including important ecosystems located in Latin America and the Caribbean, where high biodiversity indicators are one of the main features. The fourth cluster, shown in yellow, represents the different aspects of bioremediation, highlighting the current techniques used and how they are linked to sustainable agriculture and ecological restoration.

The fifth and sixth clusters are the highest in terms of word frequency and group the most related bioeconomy keywords. Containing a total of 64 words, these items focus on bioenergy and biofuel production as the most important bioeconomy sector developed in Latin American and Caribbean countries. The fifth cluster highlights the environmental impact and the life cycle assessment as evaluation methodologies for this type of model. Bioethics, food security, and COVID-19 appear in cluster six as relevant and topical issues.

The seventh cluster, marked in orange, refers to energy efficiency, the production of oilseeds, and concepts related to the sustainable development of the bioeconomy in Latin America and the Caribbean.

Finally, the eighth cluster brings together in a single word ("bioeconomy") a holistic approach to the previous clusters and summarizes, in a few keywords, the concepts of biomass production (such as biofuels), which is considered the most important sector identified in the region in this study.

In conclusion, it can be said that the bioeconomic sectors developed in Latin America, according to the scientific articles evaluated in this research, are concentrated in the production of bioenergy. The backbone of the field studied is the production of various biofuels, with leading countries such as Brazil and Argentina, which are considered the largest producers in the region. Although other types of biomass production in LAC were included in the keyword search, no words or clusters were found in the results.

3.4. Mapping of Topic-Evolution

Figure 7 examines the evolution of the topic map of the main research directions in recent years. Among the motor themes, three basic directions can be observed: firstly, the growing importance of bioenergy as a general category, including biofuels and other types of renewable energy; secondly, biomass as a primary source for bioenergy production; and thirdly, climate change as a cross-cutting theme of the previous ones since it is directly related to the production of biofuels as a strategy to mitigate the climate impact of fossil fuels. No basic topics are reported in this period of the research.

According to Plaza-Delgado E. et al., an alternative to reduce the consumption of fossil fuels is the use of biomass as a source of energy, especially in the Latin American and Caribbean region, which has great potential due to its diverse sources of biomass [49]. The study by Bailis R. et al. points out that this region is a world leader in the production of biofuels, accounting for 27% of the world's supply [50]. However, it is important to consider that the production of biofuels could mean an expansion of the production frontier, which poses a serious challenge to the region's environment and biodiversity [51].

Finally, bioethics is still present as an emerging theme in the analysis; according to Gutierrez-Prieto, Hin the last thirty years, Bioethics, as a developing discipline, has obtained gradual and increasing worldwide recognition, not only for its novelty but also for the connection with the future research topics [39]. In the same vein, the Nuffield Council on Bioethics highlighted the ethical issues raised by current and future approaches to biofuel development, as global biofuel production indirectly has serious negative impacts on agricultural and food sustainability [52].

In conclusion, scientific research on the region's bioeconomic sectors in the period 2015 to 2021 has focused on bioenergy as a fundamental strategy in both ways, on the one hand in relation to the production of biofuels as an energy source, and on the other as a transitional energy model for some Latin American and Caribbean countries.

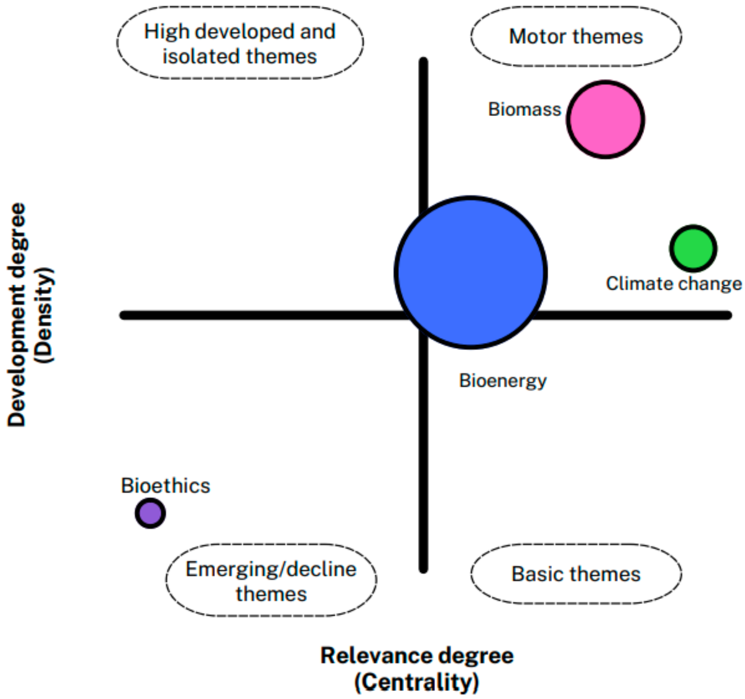

Figure 7. Science map of research topics from 2015 to 2021.

4. Discussion

The results of the bibliometric analysis have highlighted the importance of biofuels as the most important sector of the bioeconomy developed in the Latin America and Caribbean countries evaluated. This finding is in support of the fact that the number of relevant publications in this area has been growing exponentially. Aydogan H. et al. pointed out that biofuels have been rapidly gaining prominence due to their continuous increase in economic value and, at the same time, less harmful effects on the environment [6,30,53].

According to the IICA study, by 2020 Brazil will be the world's second-largest producer of liquid biofuels, with a 23 percent share, behind the United States [54]. On the other hand, Argentina has a significant share in world biodiesel production, with around 7 percent, followed by Thailand, Colombia, and Paraguay [55,56].

Our research has also highlighted the relationship between biofuels and land use, particularly the crops used as feedstock for their production, and their transversal link to the region's ongoing concerns about food security and the sustainable development of such products. The World Bank's 2008 Development Report of Agriculture Development notes that the major challenge for governments in developing countries, such as those in Latin America and the Caribbean, is to "implement regulations and to develop certification systems that reduce the environmental and food security risks of biofuel production" [57].

The sustainability of agricultural land use for biofuel production is one of the priority issues to be discussed in the future, given the importance of biofuels as a major sector in the region. According to UNCTAD, biofuels compete directly with existing arable and grazing land for food production [58]. Moreover, bioenergy crops can lead to agricultural expansion, competition for water, and threats to biodiversity, especially in rural LAC areas with high ecological and social vulnerability [59].

Climate change was another cluster identified within the keyword analysis that is directly related to biofuels. Jeswani H et al. [60] point out that biofuels do not exist in isolation and, like other production systems, have an impact on various ecosystem services such as land, water, and food. In addition, authors such as Prasad, S. et al. [61] point out that producing biofuels from biomass has the potential to promote sustainable development and mitigate climate change while providing socio-economic benefits.

In terms of scientific publications, Latin American and Caribbean countries such as Brazil, Argentina, Mexico, and Chile are among the top twenty countries in terms of scientific production over the last period. This reflects a positive evolution in the concentration of developing countries as producers of scientific publications, compared to previous years when developed countries such as the United States had a significant and majority participation. However, the research shows that in terms of the most relevant scientific journals, the majority of them are from European countries or the United States. The representativeness of journals from Latin American and Caribbean countries is very low, even though the topics covered are directly related to this region.

With regard to the other types of bioeconomy sectors based on the final products obtained from biomass, we did not find any significant scientific publications in the Latin American and Caribbean countries evaluated during the period under review. However, the region has a wide and diverse range of renewable natural resources that could provide the essential basis for the development of a competitive bioeconomy [62] and the production of innovative products with added bioeconomic value [63].

Within the clustering of research topics, we could identify important keywords such as 'bioethics', 'food security', and 'COVID', which are transversally related to the bioeconomy sectors and also represent current topics in the scientific fields. According to Woźniak E et al., the "COVID crisis may be the driving force for the global integration related to bioeconomy, especially in implementing the SGD goals, development of national and regional bioeconomy strategies, ensuring food security and protecting biodiversity" [64]. Regarding bioethics as an emerging term, several bibliographical references indicate its importance over time and its close relationship with bioeconomy sectors, especially those environmental and sustainable aspects that seek social agreements to support human well-being while preserving the natural environment [65].

Finally, the structural breakpoints in the research database have been able to indicate the importance of bioeconomy sectors over time. It is noteworthy that since 2013, several European countries, including Germany, Spain, and Finland, proposed major policies to develop their bioeconomy, followed by several public policy documents and research papers covering different aspects of bioeconomy in developing countries at local and national levels [66].

5. Conclusions

The study highlights the importance of biofuels as the most important bioeconomy sector developed in the Latin American and Caribbean countries evaluated. Brazil and Argentina are the region's main producers and rank first in the world. Even though the region has a wide and diverse range of renewable natural resources, we were not able to find any significant scientific publications on other types of bioeconomy sectors that are based on the final products obtained from biomass.

Based on the co-occurrence keywords, our research has also shown the relationship between the eight identified clusters: (1) agriculture; (2) climate change; (3) diversity; (4) bioremediation; (5) bioenergy; (6) biofuels; (7) energy efficiency; and (8) bioeconomy. The first seven are linked to the region's current concerns for food security and the sustainable development of bioenergy production, while the eighth relates to the holistic approach of the research. In terms of scientific production in recent years, Brazil, Argentina, Mexico, and Chile are at the top positions. However, the research shows that the most relevant scientific journals belong to developed European countries or the United States.

In conclusion, in the LAC countries under review, there has been a significant increase in scientific production in relation to bioeconomy sectors over the last 15 years, with the main focus of research on biofuel production as the main source of bioenergy. The above results highlight the significant research gap on other types of innovative products with bioeconomic added value that could be generated in the region, given its immense biodiversity potential.

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Appendix A

Statistical analysis completed by using "Gretl software" to corroborate the structural breakpoints established by the R-package of the main dataset and the historical records mentioned in Table 1.

Model 1: OLS using observations 1997-2021 (T=45)

Depended Variable: Years Production

	Coefficient	std. error	t-radio	p-value
Const	-357.033	59.4080	-6.010	3.54×10^{7} ***
Time	33.8536	2.24916	15.05	9.54×10^{19}***

Mean depend variable	421.6000	S.D. depend var	484.9947
Sum squared resid	1651018	S.E. of regression	195.9484
R- squared	0.840476	Adjusted R-squared	0.836766
F (1,43)	226.5524	P- values (F)	9.54×10^{19}
Long likelihood	-300.3326	Akaike criterion	604.6653
Schwarz criterion	608.2786	Hannan-Quinn	606.0126
Rho	0.949934	Durbin-Watson	0.072092

Chow test for structural break at observation 2000 –
Null Hypothesis: no structural break
Test Statistic: F (2, 41) = 208.784
with p-value= P (F (2, 41) > 208.784) = 3.18626×10^{22}

Chow test for structural break at observation 2007 –
Null Hypothesis: no structural break
Test Statistic: F (2, 41) = 272.063
with p-value= P (F (2, 41) > 272.063) = 2.15505×10^{24}

Chow test for structural break at observation 2014 –
Null Hypothesis: no structural break
Test Statistic: F (2, 41) = 36.8912
with p-value= P (F (2, 41) > 36.8912) = 6.83324×10^{10}

Figure A1. Article year's production of the main dataset (***: $p \leq 0.001$).

Model 1: OLS using observations 1997-2020 (T=44)

Depended Variable: PrimaryEnergySupplyLAC

	Coefficient	std. error	t-radio	p-value
Const	124266	7989.66	15.55	4.92×10^{19} ***
Time	13.993.4	309.245	45.55	2.88×10^{37}***

Mean depend variable	439117.9	S.D. depend var	181582.8
Sum squared resid	2.85×10^{10}	S.E. of regression	26248.26
R- squared	0.979900	Adjusted R-squared	0.979422
F (1,43)	2847.587	P- values (F)	2.88×10^{37}
Long likelihood	-507.7889	Akaike criterion	1021.578
Schwarz criterion	1025.146	Hannan-Quinn	1022.901
Rho	0.794095	Durbin-Watson	0.387197

Chow test for structural break at observation 2000 –
Null Hypothesis: no structural break
Test Statistic: F (2, 40) = 28.029
with p-value= P (F (2, 40) > 28.029) = 2.48453×10^{08}
Chow test for structural break at observation 2007 –
Null Hypothesis: no structural break
Test Statistic: F (2, 40) = 30.0038
with p-value= P (F (2, 40) > 30.0038) = 1.097084×10^{08}
Chow test for structural break at observation 2014 –
Null Hypothesis: no structural break
Test Statistic: F (2, 40) = 3.6204
with p-value= P (F (2, 40) > 3.6204) = 0.0358802

Figure A2. Primary energy supply from renewable sources in Latin American and Caribbean countries. (***: $p \leq 0.001$).

Model 1: OLS using observations 1997-2019 (T=30)

Depended Variable: GlobalRenewableConsumption

	Coefficient	std. error	t-radio	p-value
Const	5.66437	0.187839	30.16	6.83×10^{23} ***
Time	0.163804	0.0105807	15.48	2.96×10^{15}***

Mean depend variable	8.203333	S.D. depend var	1.523943
Sum squared resid	7.045141	S.E. of regression	0.501610
R- squared	0.895395	Adjusted R-squared	0.891659
F (1,43)	239.6725	P- values (F)	2.96×10^{15}
Long likelihood	-20.83527	Akaike criterion	45.67053
Schwarz criterion	48.47293	Hannan-Quinn	46.56704
Rho	0.942290	Durbin-Watson	0.175627

Chow test for structural break at observation 2000 –
Null Hypothesis: no structural break
Test Statistic: F (2, 26) = 36.5613
with p-value= P (F (2, 26) > 36.5613) = 2.78235×10^{08}
Chow test for structural break at observation 2007 –
Null Hypothesis: no structural break
Test Statistic: F (2, 26) = 141.826
with p-value= P (F (2, 26) > 141.826) = 1.03109×10^{14}
Chow test for structural break at observation 2014 –
Null Hypothesis: no structural break
Test Statistic: F (2, 26) = 26.554
with p-value= P (F (2, 26) > 26.554) = 5.2215×10^{07}

Figure A3. Renewable share (modern renewables) in final energy consumption, word wide (***: $p \leq 0.001$).

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