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Bioeconomy: bibliometric analysis from 2006 to 2019

Bioeconomía: análisis bibliométrico 2006 a 2019

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Abstract
This research aimed at the understanding of bioeconomy through the exploration of scientific studies related to the concept in academic literature. A bibliometric analysis was carried out with 2.321 publications in the Web of Science database between 2006-2019. The structural analysis of the work in bioeconomy showed that there is a high rate of cooperation with a rich research network between institutions of European countries (8 of 11 groups) and comparatively a low level of collaboration with other nations.
key words: bioeconomy, bibliometric analysis, biotechnology

Resumen
Esta investigación tuvo como objetivo la comprensión de la bioeconomía a través de la exploración de estudios científicos relacionados con el concepto en la literatura académica. Se realizó un análisis bibliométrico con 2.321 publicaciones en la base de datos de Web of Science entre 2006-2019. El análisis estructural del trabajo en bioeconomía mostró que existe una alta tasa de cooperación con una rica red de investigación entre instituciones de países europeos (8 de 11 grupos) y comparativamente un bajo nivel de colaboración con otras naciones.
Palabras clave: bioeconomía, análisis bibliométrico, biotecnología

1. Introduction

Sustained economic growth is one of the goals of every nation and is defined as an increase in the utility or value of goods and services to ensure higher standards of living alongside high purchasing power, employment, and tax revenues through variables such as: investment, consumption, government, policies to encourage savings among other economic variables as driving forces (WTO,2019). Likewise, over time, human beings have made use of natural resources to satisfy basic needs like any other living being, generating as a consequence, the modification of their environment by employing increasingly powerful skills and tools for the exploitation of natural resources that were previously considered inexhaustible and rapidly renewing by themselves. However, due to technological advances, it has been evidenced that the earth's resources do not exactly fit into the categories of *renewable or non-renewable.* In general, they are slowly repairable; however, at present their rate of degradation exceeds their natural rate of regeneration. In other words, land that is wasted or lost through degradation is not naturally replaced in the course of a human lifetime, thus resulting in a loss of opportunities

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for subsequent generations. In fact, we are currently facing one of the worst environmental crises in history, given to the fact that 33% of the land is highly degraded because of chemical contamination of the soil, erosion, salinization and consumerist society that is increasingly demanding products with special characteristics that demand large amounts of fossil energy. Resulting in the formation of pollution sources, since at all stages of product manufacture, from the extraction of raw materials to the disposal of the final product, there is a notable environmental impact that leaves liquid, solid and gaseous waste behind. (FAO, 2015).

Nicholas Georgescu-Roegen, illustrious mathematician, statistician and prestigious Romanian economist is considered as one of the precursors and father of the concept of bioeconomy. In 1971 he published his work called Law of Entropy and the Economic Process in English, whose Spanish translation first appeared in 1996 and in global terms emphasizes that the economy must move to think in terms of the ecosystem (Maldonado, 2012). On the other hand, the Bioeconomy or Biological Economy is a model of production in full evolution given its transversal nature related to all the socioeconomic, biological, and ethical activities. Generally speaking, it addresses global challenges such as the scarcity of natural resources, climate change, intensive use of fossil resources, food security, waste flow and its conservation in products with added value (food, bio-plastics, bio-fertilizers) and the management of available resources for sustainable economic development. It is based on replacing the use of fossil-based raw materials with biomass (organic or vegetable matter), for the generation of energy and fuel, as well as the production, conservation, and reuse of renewable biological resources (Ramos, 2016). Applying biological principles and processes in different sectors of the economy generate an innovative use that provides opportunities to contribute to several of the objectives of Sustainable Development (SD) designed to improve social, economic, and ecological life. In relation to the above issues, in 2015, 62 ministers met at the Global Forum for Food and Agriculture (GFFA) in Berlin, suggesting that FAO coordinate international work to establish guidelines on **sustainable bioeconomy.**

Nonetheless, the application and definition of bioeconomy is still being discussed by international agencies such as the OECD (Organization for Economic Cooperation and Development), the European Commission (EC), and some developed countries and is still a subject of discussion given its different approaches. The term bioeconomy was probably first used at a meeting of the American Association for the Advancement of Science in 1997. During Barack Obama's presidential term, an official strategy on bioeconomy was launched called the "National Bioeconomy Plan" (The White House, 2012a), in the official document the term bioeconomy is defined: “The bioeconomy is based on the use of research and innovation in the life sciences to create economic activity and public benefit. The U.S. bioeconomy represents everything around us: new medicines and diagnostics to improve human health, higher-yielding food crops, emerging biofuels to reduce dependence on oil, and bio-based chemical intermediates, to name a few" (The White House, 2012b). This perspective on the bioeconomy encompasses two important aspects: biotechnological innovation and resource substitution.

The United States is not the only region of the world where the concept of the bioeconomy has been promoted, as previously mentioned, the expression of bioeconomy was first introduced by scientists uneasy about the industrial consequences of advances in biology, and thus members of the European Commission staff decided on making the bioeconomy a policy concept to be promoted, given its unique potential to respond to new opportunities in biotechnology. One of the key representatives in this effort was Christian Patermann, former director of the "Biotechnology, Agriculture and Nutrition" Programme in the European Commission's Directorate-General for Research, Science, and Education, who promoted within the Commission the turning of the Bioeconomy into a state policy.

The European Union (EU) in developing the concept of the bioeconomy in the first decade of the 2000s attached the label "knowledge-based" as it was in line with the EU innovation policy that prevailed at that time. The concept of the knowledge-based economy refers to the vision of achieving economic growth through high-tech industries, which would require investment in various areas in terms of innovation and highly skilled labor. In 2007 the German Presidency of the European Union Council held a workshop in the city of Cologne attended by experts from research organizations, companies from different fields including crop production, biotechnology, bioenergy, and biomedicine. The Cologne Document emphasized the role of biotechnology as "an important pillar of Europe's economy for 2030, indispensable for sustainable economic growth, employment, energy supply and the maintenance of living standards". In addition, the emphasis was placed on the use of crops as renewable industrial feedstocks to produce biofuels, biopolymers, and chemicals (EU, 2007).

Other countries have also published policies and strategies related to the bioeconomy. For instance, Malaysia published the "Bio-economy Transformation Programme" in 2012, and South Africa launched a bio-economy strategy in 2013. It is worth mentioning that although many countries do not yet have policies on the subject, there is a large amount of countries that have strategies related to biotechnology and/or renewable resources (Council, 2015b). Among the Asian countries like China, it is possible to identify the adoption of explicit strategies in bioeconomy among which stand out: 12th five-year plan (2011-2015) in agricultural sciences and technological development, implemented by the Ministry of Agriculture and 13th five-year plan (2016-2020) for the social and economic development of the people of the Republic of China, designed by the Central Committee of the Communist Party of China both initiatives oriented to the substitution of fuels by materials with biological bases (Dietz, Börner, Förster, & von Braun, 2018).

In Latin America and in the Caribbean the concept of bioeconomy has gained relevance in recent years, given the opportunity that the region has as a major producer of biomass and the considerable progress in scientific and technological issues in the development of bio-energy and industrial infrastructure. In 2015 the regional seminar on Bioeconomy in Latin America and The Caribbean was oriented, where future ideas were established to be developed as:

a) Promoting dialogue between public and private parties interested in the bioeconomy.
b) Strengthening social understanding of the potential of the bioeconomy to guarantee competitive development.
c) Exchanging significant experiences between public and private sector entities (university and business) in Bioeconomy related to business and market development.
d) The testing of routes for the promotion of the bioeconomy.
e) e) Raising bioeconomy to a higher political level that will improve environments and enable more inclusive societies.

In Latin America, Argentina is one of the countries with the greatest progress in bioeconomy with specific actions among which it is worth mentioning the creation of the Board of Directors (National Council on Bioeconomy) in 2017, where the work on a roadmap for development in this area formally began with the primary goal of generating greater use of opportunities for innovation in biotechnology.

Subsequently, we find Brazil with policies in different areas of the bioeconomy among which we show some initiatives implemented in 2011 with the establishment of the Action Plan for Sustainable Production and Consumption (PPCS) by the Ministry of Environment, to guide and coordinate more sustainable production and consumption methods. In relation to Colombia, the relevant advances in public policy for the bioeconomy are established in the Political Constitution of 1991, since it incorporates the needed institutional framework for the management of biodiversity and environmental care. Among the advances for the development of the bioeconomy, the National Council for Economic and Social Policy (CONPES by its Spanish initials) has established documents such the CONPES 3697 (June 2011) which stands out on policies for the commercial development of biotechnology based on the sustainable use of biodiversity. Another relevant aspect is the CONPES 3834 document, published in 2015, regarding policies to stimulate private investment in Science, technology, and innovation (Rodriguez, 2018) and more recently the CONPES 3934 (July 2018) on green growth policy to promote increased productivity and economic competitiveness of the country by ensuring the sustainable use and social inclusion in a climate-compatible manner by 2030. (Rodriguez, 2018)

Finally, this article aims to provide some considerations about the concept and approach of bioeconomy, as well as to explore the origins, absorption, and contents of the term "Bioeconomy" in the academic literature. Including a bibliometric analysis in which the annual scientific production from 2006 to the beginning of 2020, the main journals in which it is published on the subject, the main authors worldwide and their institutional affiliation are presented. A structural analysis was then carried out showing the collaborative working relationships (co-authorship between authors and peer-reviewed articles on the topic, central organizations, countries, and scientific fields).

Table 1

Progress in Latin America in the formulation of policies for the development of the bioeconomy

Country	Background	Reasons to promote the development of the Bioeconomy in the country	Ongoing actions	Challenges
Argentina	In 2017, the Agreement was signed and its Board of Directors (National Bioeconomy Council) was constituted and formal work began on a roadmap for the development of the Argentine bioeconomy.	The potential to contribute is recognized: a). To strengthen productive diversification and creation of added value at the regional and local level; b) To generate jobs at the local level and facilitate the reintegration of the labor force that migrates from agriculture; d) To promote occupation and land use planning on the basis of new production schemes; and e) To promote the concepts of environmental sustainability and social inclusion.	To promote, when necessary, the adaptation of institutional frameworks, (legislative and regulatory) to the characteristic requirements of the bioeconomy; • strengthen and coordinate the supply of financing instruments to promote activities related to the bioeconomy.	The Integration of the bioeconomy vision into existing public policy frameworks (for example, in terms of resources, mainstreaming, business models, trade policies, etc.).
Brazil	The Action Plan for Sustainable Production and Consumption (PPCS), established in 2011 by the Brazilian Ministry of the Environment, to guide and coordinate more sustainable production and consumption methods. This plan links the country's main environmental and development policies, especially the National Policy on Climate Change and Solid Waste and the Brazilian industrial policy (Plano Brasil Maior) (Il Bioeconomista, 2015).	It is considered one of the mega-diverse countries; 6 large biomes are identified: The Amazon, the Cerrado, the Mata Atlantica, the Caatinga, the Pampa and the Pantanal. It is considered the first country in the world in terms of the potential use of its biodiversity	In the private sector, work has been done on the preparation of a proposal for a Bioeconomy Agenda, the result of work forums led by the National Confederation of Industry during the years 2011 to 2013. This agenda presents three dimensions and convergent actions to obtain results scientific, technological, and business. technological and business. The dimensions are industrial biotechnology, the primary sector and human health.	Strengthening the scientific-technological base

Country	Background	Reasons to promote the development of the Bioeconomy in the country	Ongoing actions	Challenges
Costa Rica	In terms of national plans and strategies, the following stand out: * 2016, National Policy of Society and Economy based on Knowledge. 2017-2030; • 2017, National Wetland Policy, 2017-2030.	Several factors are conducive to the development of the bioeconomy in Costa Rica: a) the existence of legal frameworks and institutionality (see previous section); b) the existence of relevant national policies and strategies (see previous section); and c) high biodiversity and the existence of policies for its management.	A 2018-2020 route has been defined, which contemplates the creation of an Interministerial Committee for the Bioeconomy (2018), in which the private sector would be integrated (2019). The survey and analysis of relevant ongoing actions and the prioritization of activities (2018), as well as the identification and analysis of existing regulations (2019) are also contemplated.	Challenges are identified in terms of: a) achieving a coherent integration of the strategic and legal frameworks relevant to the bioeconomy and the circular economy; b) the need to articulate many institutions, in relevant fields (e.g. science and technology and innovation, environment, agriculture, health, industry, commerce); c) the integration of the different perspectives of public and private actors, academics and civil society.
Ecuador	Among the main antecedents in the development of strategies in areas related to the bioeconomy are the realization of a seminar on bioknowledge (2011), the Strategy of Productive Matrix Change and the Natural Heritage Governance Policy (2013), the implementation of the Program Socio-Bosque (2015) and the National Biodiversity Strategy 2030 “Bioindustria” (2016).	Between June and December 2017, a Bioeconomy Working Group was established within the Ministry and a conceptualization process began to be developed, which has laid the foundations for the process of preparing a Bioeconomy Public Policy.	The bioeconomy included as a strategic area in the National Development Plan 2017-2021, the National Biodiversity Strategy 2030.	To officialize a public policy on bioeconomy

Source: Based on information provided by (Rodriguez, 2018) related to bioeconomy in Latin America and The Caribbean.

2. Methods and data collection

This was a retrospective and descriptive bibliometric study, conducted through Web of Science. Publication data was searched and downloaded for this study from Clarivate Analytics (formerly known as Thomson Reuters) Web of Science (WoS) product name (https://mjl.clarivate.com/). WoS covers the Expanded Science Citation Index and the Social Science Citation Index and is widely used in the academic domain around the world. The search strategy was carried out on 16 December 2019, by providing the thematic keyword "Bioeconomy" with an enabled time interval of "every year". The database provided information since 2006 and articles published in advance for the year 2020. With the aim of covering the maximum number of publications and types of documents, the option "All types” was selected. A total of 2321 publications met the search criteria, with the search based mainly on 2 types of documents, articles, and reviews. Table 2 includes data on all types of documents that were used in the analysis and their percentage distribution

Table 2
Types of documents analyzed and percentage distribution in the period 2006-2020.

Document Types	Number	%
Article	1770	76.26
Article; Book Chapter	6	0.26
Article; Data Paper	3	0.13
Article; Early Access	16	0.69
Article; Procedural Document	71	3.06
Book Review	17	0.73
Correction	2	0.09
Editorial Material	91	3.92
Summary Of The Meeting	29	1.25
New Articles	24	1.03
Revision	289	12.45
Revision; Book Chapter	1	0.04
Revision; Early Access	2	0.09
Total	2321	100

2.1. Programs for analysis

The bibliometrix R package (http://www.bibliometrix.org) provides a set of tools for quantitative research in bibliometrics and scientometrics. This program is written in the R language, which is an open code-source environment and ecosystem. The existence of substantial and effective statistical algorithms, access to high quality numerical routines and the integrated data visualization tools are perhaps the strongest qualities that distinguish R from other languages for scientific computing (Aria & Cuccurullo, 2017).

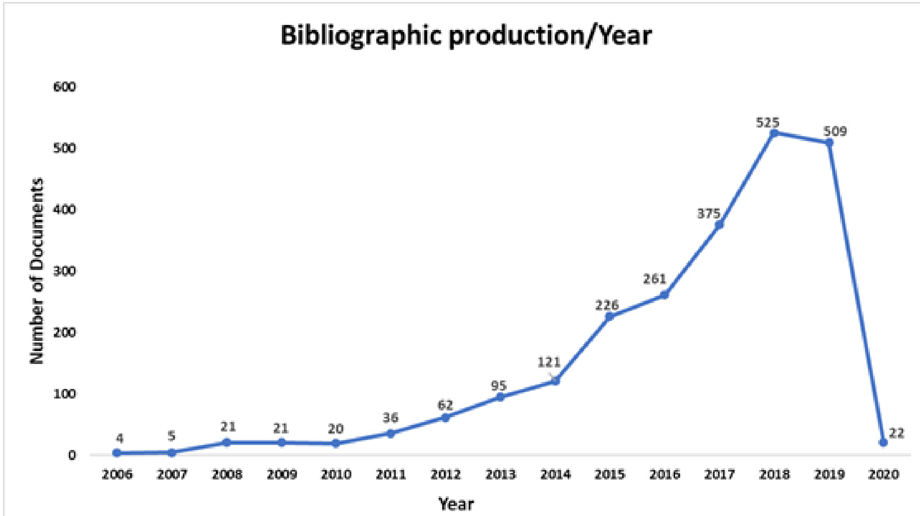
Data retrieved from the WoS site were analyzed using R study v.1.1.456, R v.3.5.1 (2018-07-02) and bibliometrix R-package (http://www.bibliometrix.org) (Aria & Cuccurullo, 2019). The generation of the graphics was carried out using the biblioshiny application. The data were mapped according to the subject of studies, using the visualization program VOS (Visualization of Similarity) (Van Eck and Waltman 2010, 2014b; www.vosviewer.com), to show the scientific landscape, the geometric scientific relationships especially complex as the co-citation and co-word occurrence analysis in bioeconomy research.

3. Data analysis and results

3.1. Annual Scientific Production

The annual trends of scientific production in terms of publications are represented in Figure 1. The reported production data is shown in the database used (WoS) since 2006, although it has been identified in other databases (unshown data) that the first report on the use of the word bioeconomy in publications was from 1979 (Ikeda, 1979). It is evidenced that between 2006 and 2011, the growth in the number of publications was not very noticeable. However, since 2012 the growth has been significant, going from 62 to 509 publications in 2019. The notable increase in the period 2012-2018 is related to the strategies developed worldwide to promote the bioeconomy (Konstantinis, Rozakis, Maria, & Shu, 2018). 2018 was the most productive year with 525 registered publications, followed by 2019 with 509 publications. Among the analysis spectrum, the year with the lowest number of publications was 2006 with 4 publications.

Figure 1
Annual Scientific Production of bioeconomy



3.2. The 25 most productive sources exhibited with publications

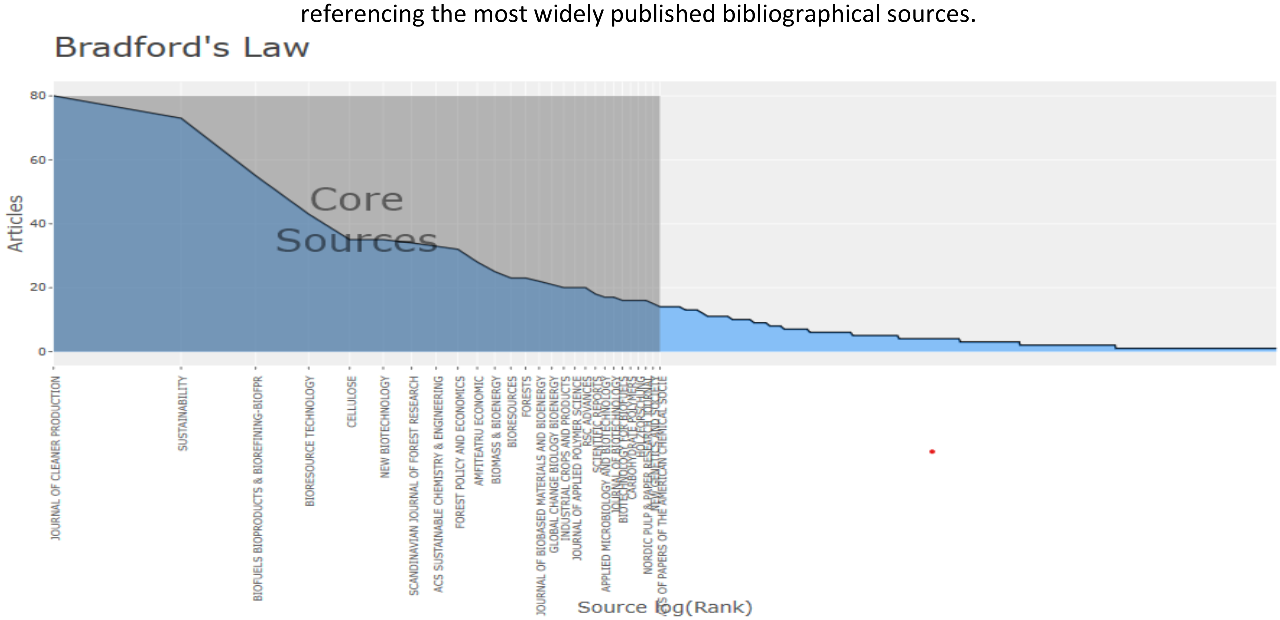
Of all the 2321 registered publications, 1770 were journal articles. From the total of journals, those with from 67 published articles to those with only 1 published article were identified. The most productive journal, which was identified with a maximum of 80 publications, is the JOURNAL OF CLEANER PRODUCTION, followed by the SUSTAINABILITY journal with 73 publications, being these the only journals with over 70 publications on the subject as evidenced in table 3. Figure 2 shows the journals that consolidate the core of knowledge, with the largest number of publications on the subject of bioeconomy as established by the Bradford Law (Urbizagástegui Alvarado, 2016).

Table 3
The 25 most relevant journals
in bioeconomy

Sources	No. Articles
Journal of cleaner production	80
Sustainability	73
Biofuels bioproducts & biorefining-biofpr	54
Bioresource technology	43
New biotechnology	35
Acs sustainable chemistry & engineering	33
Cellulose	33
Scandinavian journal of forest research	33
Forest policy and economics	32
Amfiteatru economic	28
Biomass & bioenergy	25
Bioresources	23
Forests	23
Journal of biobased materials and bioenergy	22
Global change biology bioenergy	21
Industrial crops and products	20
Rsc advances	20
Journal of applied polymer science	19
Scientific reports	18
Applied microbiology and biotechnology	17
Journal of biotechnology	17

Biotechnology for biofuels	16
Carbohydrate polymers	16
Holzforschung	16
Nordic pulp & paper research journal	16

Figure 2
Representation of Bradford's law for the term bioeconomy
referencing the most widely published bibliographical sources.



3.3. Author productivity in terms of h-index, g-index, m-index, Total Citations (TC) and Total Publications (TP)

Jorge Eduardo Hirsch, an Argentinean professor of American physics who in 2005 invented the h index. The index is based on the distribution of citations from the publications of an individual author. The h-index is an author-level matrix that can be defined as an author having an h-index of "h" when they have "h" documents that have been cited at least "h" number of times. The h-index was treated as a reliable and authentic tool for mapping the scientific contribution achieved by an individual author (Hirsch, 2005). The g-index was proposed by Leo Egghe as a modified version of the h-index and was formulated after organizing all the publications in decreasing order of citations they received; the g-index is the highest number in articles that received g-citations together (Egghe, 2006).

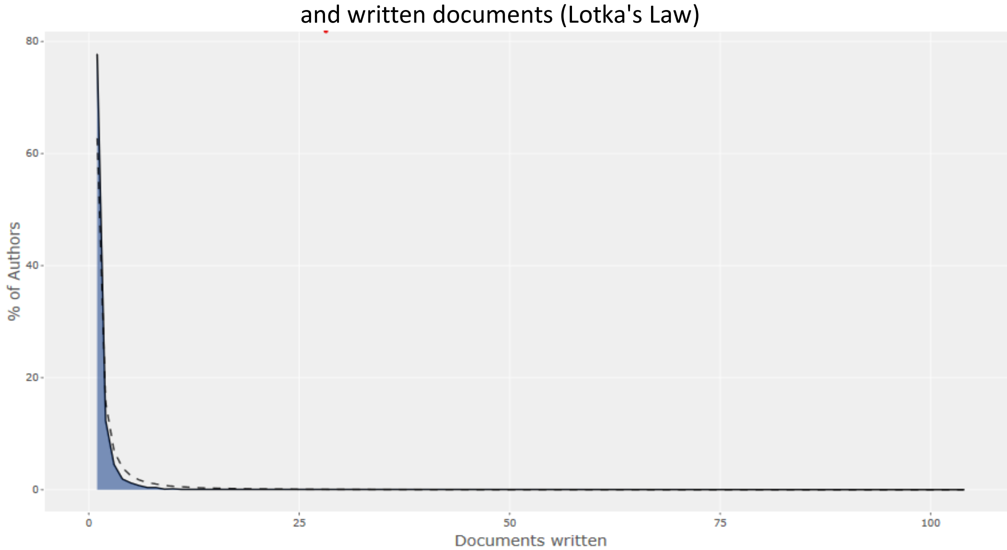
Table 3 shows the 20 best authors and their level of productivity based on the following parameters: the total number of publications (NP), total number of citations (TC), the h and g indices in bioeconomy research and the relationship between the number of authors and the number of publications generated on the topic. It should be noted that there are two authors, Misra, M and Mohanty AK, with the highest values of h and g index, both assigned to the School of Engineering of the University of Guelph - Canada.

Additionally, Figure 3 represents Lotka's law, which describes the frequency of publications by some authors on the subject (Lotka, 1926). For the specific topic of bioeconomy, we found that most authors have few publications (5523 authors with 1 article each) and there is a very small percentage of authors with a high level of production in the topic (1 author with 104 articles).

Table 4
The 20 authors with the highest productivity in bioeconomy

Author	h_index	g_index	TC	NP
Misra M	24	41	2026	104
Mohanty AK	21	41	1966	92
Sixta H	15	25	675	40
Brown Rc	14	23	562	32
Cheng YT	12	22	503	26
Pagliaro M	8	17	323	19
Toppinen A	7	17	308	19
Van Breusegem F	13	17	835	17
Ciriminna R	8	16	316	16
Kilpelainen I	11	16	343	16
Mohan SV	6	16	345	16
Jaeger KE	4	8	74	15
Johansson LS	8	11	145	15
Leskinen P	7	14	209	15
Thran D	6	8	85	15
King Awt	10	14	321	14
Rojas OJ	8	14	198	14
Usadel B	6	10	117	14
Bezama A	7	10	125	13
Dissmeyer N	9	13	230	13

Figure 3
Relationship between number of authors and written documents (Lotka's Law)



3.4. Most cited country, citations of articles and average number of citations obtained in Bioeconomy publications.

Table 4 shows the 20 most cited countries in bioeconomy research, where the participation of Germany stands out with 4032 citations of 1231 articles with an average of 9.51 article citations up to the time the research was completed. This is due to the fact that in the European states very advanced strategies have been developed in sustainable bioeconomy policies, especially in Germany. These results reflect on the role of the European Union as an active partner in promoting bioeconomic transformations (Birner, 2018). However, there is still a substantial governance gap between the promotion and regulation of the bioeconomy which has led to the absence of most Eastern European countries from these developments so far. The Western Hemisphere presents yet another global region, where most individual states are moving towards comprehensive bioeconomy strategies. Different from the European bioeconomy strategy, in which some measures to regulate the bioeconomy have been integrated. Regulatory aspects that address the potential sustainability risks associated with enhancing bioeconomy are almost absent from strategies developed by countries in the Western Hemisphere. The gap between promoting and regulating the bioeconomy is therefore even greater in the Americas than in Europe. Overall, our results clarify that countries in North and South America are making significant efforts to improve their bioeconomic sectors. Again, a different picture emerges in Asia and Australia. In this region, we find many states, especially major states such as China, India, and Australia, that have adopted advanced bioeconomy strategies. However, we also find a significant number of states without explicit bioeconomic strategies based on the level of literature production. Unlike states in the Western Hemisphere, among Asian states, at least China pays some attention to the sustainability risks associated with increasing bioeconomy, as inferred from the number of articles and citations to them.

In South America, the only present country among the 20 most cited countries in bioeconomy is Brazil with 122 articles and 218 citations equivalent to an average of 5.74 article citations. In this country, the theme is led by the Ministry of the Environment, which is responsible for guiding and coordinating more sustainable production and consumption methods, focusing mainly on the sugarcane sector. (Rodriguez G, 2018)

Finally, in Africa, we find the lowest proportion of countries with bioeconomy production. However, countries in southern Africa show with their strategies they see great potential in the bioeconomy to foster their economic development in a sustainable manner. Among these countries, South Africa stands out for having developed the most advanced bioeconomy strategies that include some regulatory aspects; for instance, the release of its strategies in bioeconomy in 2013. (Council, 2015a)

Table 5

Top 20 most cited countries in bioeconomy

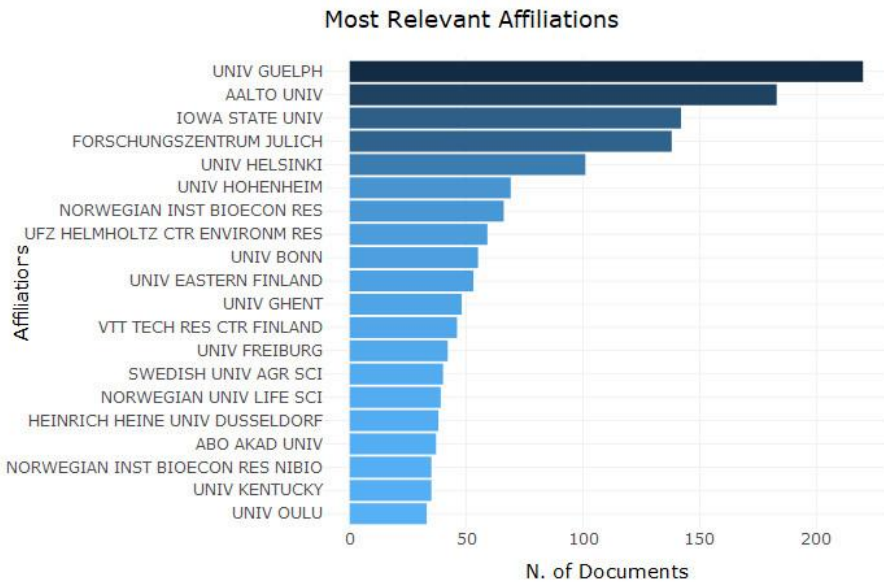
Country	Total Citations	Total Articles	Average Article
Germany	4032	1231	9.51
Finland	3702	766	10.89
Usa	3418	693	15.54
Canada	3046	397	17.41
Norway	1549	215	16.84
Uk	1321	257	12.95
Sweden	997	255	11.73
Belgium	924	143	24.32
Italy	855	222	10.56
Australia	618	118	20.60
France	593	180	12.35
India	577	90	16.03
Romania	532	171	5.54
Netherlands	395	115	15.19
Denmark	383	75	14.73
China	326	97	9.88
Spain	318	176	5.39
Austria	274	118	6.85
Brazil	218	122	5.74
South africa	178	15	25.43

3.5. Most relevant publication-related affiliations

Although the highest productivity in the field is presented in Germany (Figure 3), in terms of institutions the University of Guelph in Canada stands out at the top of the list with over 200 publications, followed by the Aalto Universities in Finland with over 160 publications; the Iowa State University in the United States and the Forschungszentrum Jülich in Germany with just under 140 publications. It is interesting to see that, among the top 10 universities, 5 are German, 2 are from Finland, 1 is from Norway, 1 is from North America, and 1 is from Canada, as seen in Figure 4.

Figure 4

The 20 most relevant institutions in the field of bioeconomy



3.6. The authors' top 20 countries

Table 5 shows the list corresponding to the main countries of affiliation to the authors, the number of total articles, the number of publications from a single country (SCP), the number of publications from multiple countries (MCP) and the ratio corresponding to the number of publications from multiple countries with reference to the total number of publications (MSP ratio).

Germany was the leading country with a total of 424 publications, of which 306 were from single countries and 118 were publications from multiple countries with an MCP ratio of 0. 278.This shows that most of the publications on bioeconomy research in Germany were published only by this country with little collaboration with other countries. In the second place, in terms of production, Finland has slightly higher value in the MCP ratio of 0.285, which shows a trend towards more working relationships in bioeconomy compared to Germany. The countries that showed more collaborative work, without implying high levels of productivity, with CCM ratio values greater than 0.5 were: The Netherlands (0.538), Austria (0.575) and China (0.697).

Table 6

Top 20 countries of the authors

Country	Articles	SCP	MCP	MCP_Ratio
Germany	424	306	118	0.278
Finland	340	243	97	0.285
Usa	220	187	33	0.15
Canada	175	147	28	0.16
United Kingdom	102	75	27	0.265

Country	Articles	SCP	MCP	MCP_Ratio
Romania	96	76	20	0.208
Norway	92	47	45	0.489
Sweden	85	48	37	0.435
Italy	81	49	32	0.395
Spain	59	36	23	0.39
France	48	33	15	0.312
Austria	40	17	23	0.575
Poland	40	31	9	0.225
Belgium	38	20	18	0.474
Brazil	38	25	13	0.342
India	36	27	9	0.25
China	33	10	23	0.697
Australia	30	18	12	0.4
Denmark	26	14	12	0.462
Netherlands	26	12	14	0.538

3.7. The 20 most cited publications

The table 6 show the list of the 20 most cited publications with their respective authors, year of publication and journals in which they were published. For instance, the publication by VAAJE-KOLSTAD G. entitled "An oxidative enzyme that increases the enzymatic conversion of recalcitrant polysaccharides" published in the journal Science in 2010 had a maximum of 499 citations in the period analyzed with a citation count of 49.9 per year. Although the aforementioned article is the most cited, the one published by Reddy in 2013 presents a higher number of references to it per year (TC per year) with a value of 62.8 which would indicate a higher research quality.

Table 7

The 20 most cited publications

Paper	Total Citations	TC per
Vaaje-Kolstad G, 2010, Science	499	49,90
Reddy Mm, 2013, Prog Polym Sci	440	62,86
Horn Sj, 2012, Biotechnol Biofuels	433	54,13
Dyer Jm, 2008, Plant J	238	19,83
Scarlat N, 2015, Environ Dev	221	44,20
Mcmichael P, 2012, J Peasant Stud	216	27,00
Mccormick K, 2013, Sustainability-Basel	206	29,43
Weigel D, 2012, Plant Physiol	199	24,88
Nagarajan V, 2016, Acs Sustain Chem Eng	183	45,75
Mohan Sv, 2016, Bioresource Technol	173	43,25
Poblete-Castro I, 2012, Appl Microbiol Biot	146	18,25
Staffas L, 2013, Sustainability-Basel	142	20,29
De Clercq I, 2013, Plant Cell	131	18,71
Muller Mm, 2012, J Biotechnol	130	16,25
Octave S, 2009, Biochimie	128	11,64
Ciriminna R, 2014, Chem Commun	125	20,83
Ng S, 2013, Plant Cell	125	17,86
Sahoo S, 2011, Biomass Bioenerg	112	12,44
Birch K, 2013, Sci Technol Hum Val	108	15,43
He Y, 2012, Biotechnol Adv	106	13,25

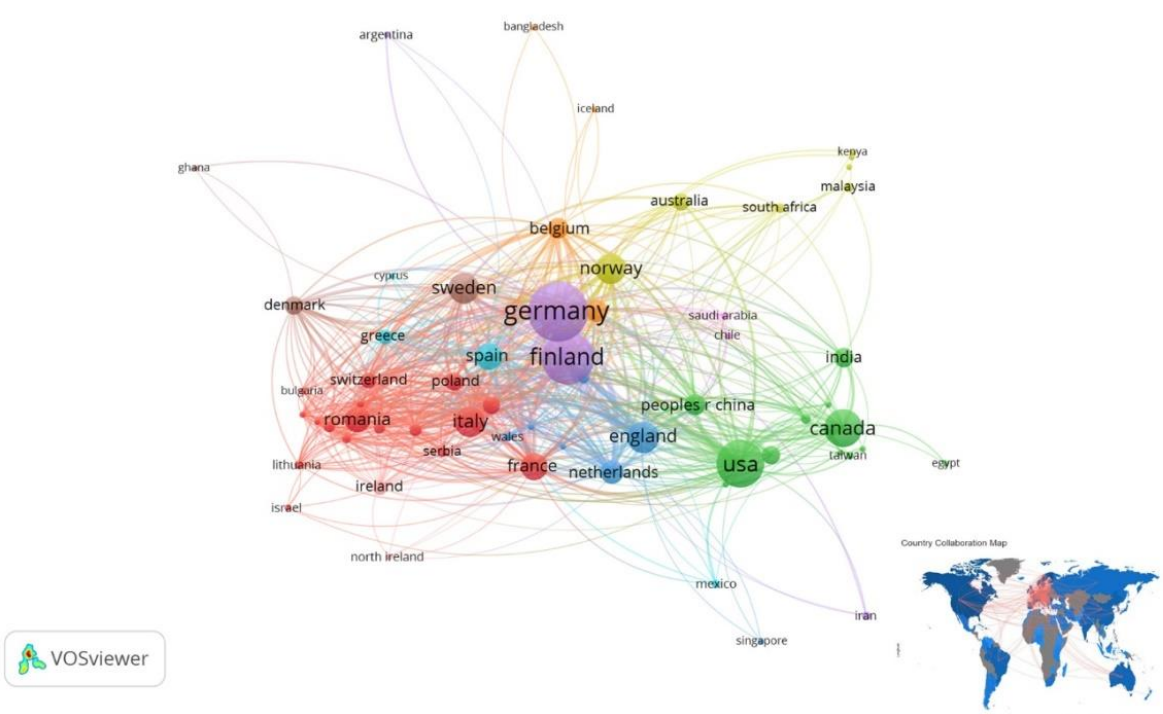
3.8. Structural analysis and visualization in bioeconomy research publications

Co-authored analysis based on countries publishing on the topic of bioeconomy

The global network of country co-authors has been created using the VOSviewer software (see Figure 9). In the figure, a node symbolizes a country, while the size of the node represents the country's activity. The curved line between the two nations shows the publishing collaboration relationship between them, finally, the thickness of the line shows the degree of collaboration between the respective countries. Criteria were established for this analysis, taking only those countries that had at least 2 publications and 2 citations for the study. The program analyzed the manually defined criteria and of the 86 countries, 63 reached the previously defined threshold. For each of the 63 countries, the total force of the co-authorship linkage to other countries was additionally calculated. The maximum number of countries that form groups and that are connected were 63, therefore, the co-authorship analysis has been carried out with the information provided by 62 countries. The software separated these 62 countries into 10 groups that form 656 cooperation links with a total link strength of 2,280. The graph shows well-established relationships between the countries, in terms of co-authorship, given that when analyzing the link lines the most are of the same thickness, a situation that may be due to the fact that the analysis spectrum was considered since 2006, and additionally, countries are currently in the process of strengthening their policies for the development of the bioeconomy. Total link strength represents the frequency of co-occurrence, and the large nodes represent the most prolific countries in terms of articles.

Figure 5 reflects that research on the bioeconomy is mainly centralized between Germany, Finland, and the United States with a great deal of mutual cooperation. Two major country groupings are established; one with 17 countries (Bulgaria, Czech Republic, Estonia, France, Hungary, Israel, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Scotland, Serbia, Slovakia, Slovenia, and Switzerland); and the other with 12 members (Brazil, Canada, Egypt, India, Indonesia, Japan, New Zealand, China, South Korea, Taiwan Thailand, and the United States). Therefore, geospatial analysis is a crucial step in discovering global cooperation in academic communication.

Figure 5
Co-authorship among countries on the topic of bioeconomy



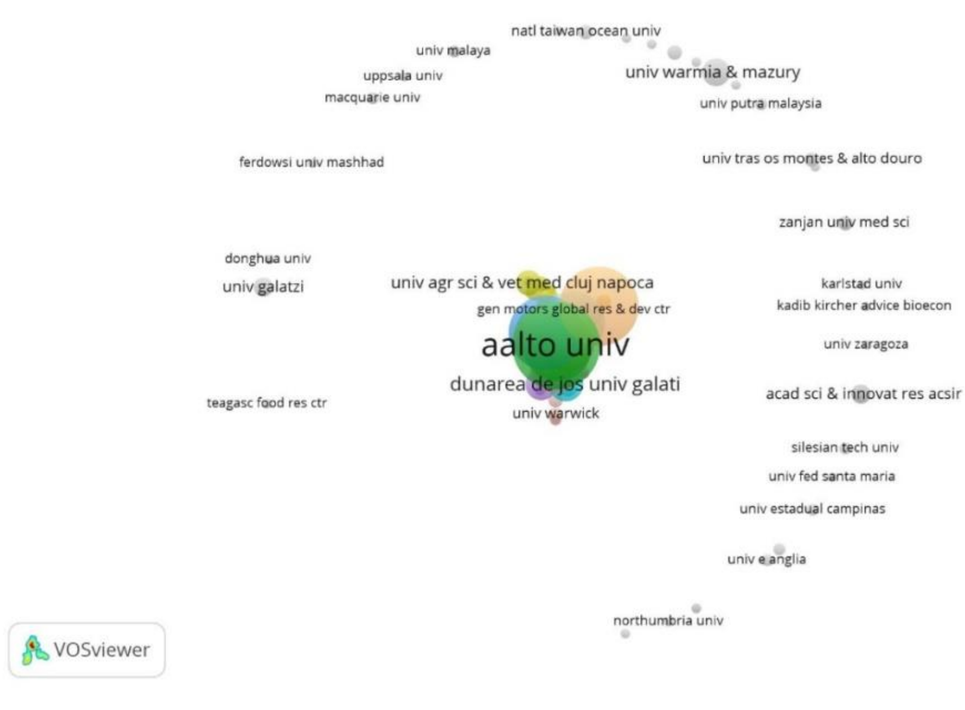
Co-authorship analysis based on the institutions that publish in the field of Bioeconomy

Table 7 shows the network of co-authorship relationships between institutions in the field of bioeconomy. The Universities of Aalto and Guelph are the two most prolific organizations worldwide in terms of numbers of articles followed by Forschungszentrum Jülich in Germany and the University of Helsinki in Finland. In North America, we find the University of Iowa to be the most active, responsible for the main co-authorship researching on this topic. Figure 6 shows the links within the network of co-authorship relationships between institutions in bioeconomy, 1962 organizations were identified, a maximum number of documents per organization of 2 was defined as analysis criteria and a minimum number of citations per organization 2, with this criterion 591 organizations were identified. No relation lines between the institutions were identified, due to the degree of dispersion of the information; locating a central grouping of universities where the most productive ones are concentrated and a large amount of universities orbiting around the central grouping with weak link strength.

Table 8
Main institutions in co-authoring activities in the field of bioeconomy.

Organization	Documents	Citations	Total link strength
Aalto Univ	136	1456	97
Univ Guelph	110	2239	2
Forrschingszentrum Julich	96	761	138
Univ Helsinki	81	1402	107
Iowa State Univ	71	1066	14
Univ Hohenheim	57	524	50
Norwegian Inst Bioecon Res	57	288	53
Rhein Westfal Th Aachen	53	577	73
Ufz Helmholtz Ctr Environm	51	649	53
Univ Eastern Finland	47	310	38

Figure 6
Institutions in co-authoring activities in the field of bioeconomy



Analysis of citations (cited sources) in publications

When two sources or authors are cited in the reference list of a document, they form a joint citation relationship; the program analyzed the cited sources used in bioeconomy research. This analysis is a potential method for assessing the overall structural horizon of any topic and its related sources. The result was a total of 856 references which were used to form 11 groupings, identifying 133,965 links between them with a total link strength of 2,550,688. Table 8 shows the ten main sources in bioeconomy with their total link strength.

Figure 7 shows the network of the density of sources cited in Bioeconomy research, the sources with higher binding strength are denser than those with lower binding strength. Bioresource technol is the most referenced journal with a total bond strength of 147,499. However, this does not mean that it is the journal with the highest productivity since, as shown in table 2, the journal with the highest number of articles is the JOURNAL OF CLEANER PRODUCTION.

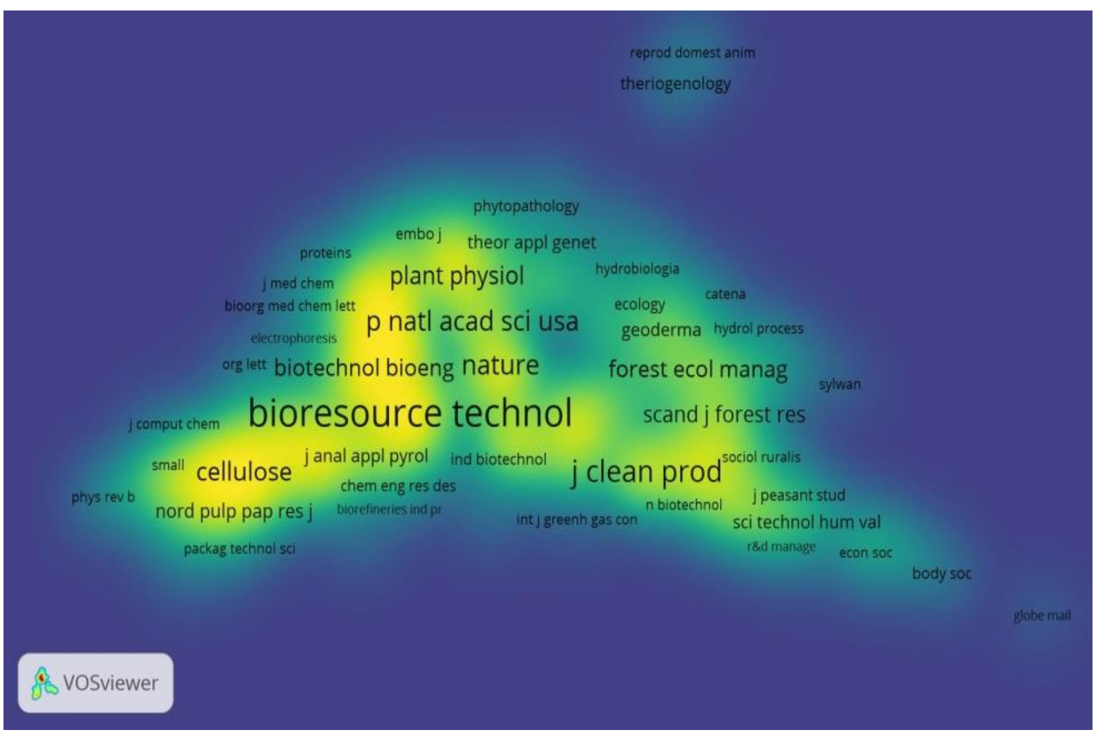
Table 9

Top ten sources with their total link strength

Source	Citations	Total link strength
Bioresouse Technol	2435	147499
Biomass Bioenerg	1374	61515
J Clean Prod	1295	55583
Science	1176	77156
P Natl Acad Aci Usa	973	79290
Appl Microbiol Biot	921	73708
Nature	906	58040
Sustainability-Based	866	33205
Renew Sust Energ Rev	827	50283
Cellulose	754	57811

Figure 7

Density analysis of citations from sources cited in bioeconomy publications.



Concurrence analysis of keywords

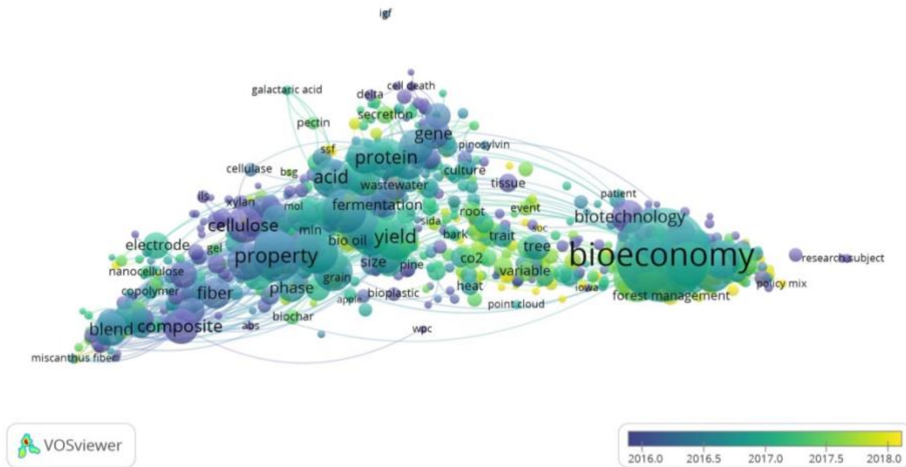
Keyword matching analyses the research entry point in a discipline, it also studies research trends in a defined domain. To build the bioeconomy scientific literature network, we use the coincidence analysis type, using the full counting method and the keywords present in the title and summary as the unit of analysis. The full counting was chosen as the counting method, a total of 50,933 terms were identified in the database, the minimum criterion of occurrence was established from the 10-word term; when this selection was made, 1,507 terms were identified that met the established limit. Based on this score, the most relevant terms were selected. The program used suggests an additional selection evaluating 60% of the most relevant terms, corresponding to 904 words. Table 9 is the list of the 10 most frequently used keywords in bioeconomic research. For each of the 81 keywords the total link strength was calculated, as expected, the most frequent keyword was bioeconomy, with a frequency of 770 and networking strength of 8622, followed by the word Effect, with a binding force of 5680 and a frequency of 434. The overlap analysis shows the coincidence of keywords in a stipulated time frame. Figure 8 shows the keywords that were presented in bioeconomy research in political, and social issues such as policy mix, forest owner, forest management; and, scientific issues such as SSF, nanocellulose, bio-oil, catibs that evolved or appeared only from early 2018 until now. It is observed that the study and development of bioeconomy are strongly linked to research in basic sciences, as evidenced by the information in the most cited article on bioeconomy "An oxidative enzyme that increases the enzymatic conversion of recalcitrant polysaccharides", an article on biochemistry and biotechnology.

Table 9
The 10 most commonly occurring
keywords used in bioeconomy research

Keyword	Occurrence	Total link strength
Bioeconomy	1533	22267
Property	442	8705
Forest	387	7435
Concentration	356	7207
Content	356	7993
Yield	354	7215
Sector	339	6287
Economy	339	5432
Policy	301	5653
Protein	290	4916

Figure 8

Co-occurrence analysis of keywords in bioeconomy research. Coverage visualization



3.8. Discussion

Based on a review of the research literature, published in the WoS database; this document compiles the scope, the main actors at the level of countries, institutions and authors, the origins, and scope of the notion on bioeconomy. In addition, the document attempts to deepen our understanding of the bibliometric topic of Bioeconomy. In summary, the paper has attempted to map the diverse motives and perspectives in this field, although some argued that the transition to the bioeconomy plays a key role in focusing on major challenges such as climate change, food security, health, industrial restructuring, and energy security; the paper shows that the bioeconomy is a young field of research. Even though it is likely that the research covered in this analysis is more related to the aforementioned domains or similar research under different headings, such as biotechnology. Unlike the earlier research on biotechnology, more recent research on the bioeconomy appears to be concerned with a broader concept covering topics from health and the chemical industry to agriculture, forestry, and bio-energy. The paper shows how a wide range of different disciplines is involved in the production of knowledge that supports the emergence of bioeconomy. This breadth reflects the generic nature of the notion of bioeconomy. However, among the variety of disciplines investigating the bioeconomy, the natural sciences and engineering play the most central role.

With this in mind, it is perhaps not surprising that the literature review identifies three visions of the bioeconomy, the biotechnological vision, the biological resources vision and the bioecological vision. The first two views are strongly influenced by engineering and natural science perspectives, emphasizing the importance of biological product improvement, processing, application, and marketing in different sectors of the economy. Regarding the bioecological vision, sustainable and ecological processes that optimize the use of energy and nutrients are highlighted, promoting biodiversity, and recommending avoiding monocultures and soil degradation.

The perception of a bioeconomy also contains different objectives in terms of a focus on the reduction and flow of bio-resource waste, on the one hand, and the development of new products of economic value based on existing bio-resource waste flows, on the other. To the extent that new economic value chains are emerging around bio-waste today, this may constitute a disincentive to reduce the amount of bio-waste in the first place. These two objectives may constitute contrasting rationalities. Such contrasting rationality reflects the diversity among the policy areas involved and highlights the difficulty of talking about horizontal policies across sectors or domains. At the same time, however, given the emphasis on engineering and the natural sciences, the biotechnological vision and the vision of biological resources overlap to some extent and may represent complementary strategies in terms of the possibility of applying biotechnology to biological resources.

In this sense, a viable strategy for countries and regions that have localized biological resources and the technology to refine and update them may be the opportunity to enhance rather than export them. National upgrading would ensure greater value creation at the local level, besides the expected synergies in terms of research and innovation. An important theme for future studies in bioeconomy, in non-technical fields, might be to provide a deeper understanding of the socio-economic aspects of bioeconomy and its potential to address the major challenges of our time. Further research on the position of the bioeconomy in social sciences would, therefore, be welcome. For example, although the master narrative surrounding the bioeconomy emphasizes environmental protection and the effects of climate change, these aspects are rarely assessed.

The paper has shown how these different visions seem to coexist in the research literature and how they have implications for the objectives, value creation, innovation drivers, and spatial approach to biological resource exploration and exploitation. Increasing knowledge in the bioeconomy may involve different ways of applying biotechnology to biological resources, and different ways of harvesting new bioproducts as well as generating a better understanding of the ecosystems in which we live and the diverse alternatives we have in terms of new sustainable solutions for managing and exploiting them.

4. Conclusions

In conclusion, we have tried in this document to trace the emergence and evolution of the concept of bioeconomy to show how it has been strategically framed and used by various constituencies as a political, scientific/technological and economic project to respond to challenges of a regional and global nature. The bioeconomy emerges as a necessity derived from environmental and economic instabilities. The current form is based on four horizons that are established as Energy demand (Biofuels, Biorefinery, Biomass, Bioenergy); land demand (Sustainability, Biotechnology, Agriculture, Policy); governance (Bioeconomy, Industrial Biotechnology, Biopolitics); and interaction with other schemes (Circular Economy, Green Economy). The transition to the bioeconomy followed the biological law stating that the accumulation of small quantitative differences leads to qualitative differentiation, that is, simple technical actions of change based on the linear model centered on how fossil resources can lead to a new model based on sustainable use of biological resources.

At the heart of the critical dispute over the bioeconomy is the finding that the path currently being followed is overly technology-dependent, both in terms of research focused on the life sciences and related technologies. According to critics, two shortcomings resulted from this limited understanding of the concept; on the one hand, an under-representation of certain disciplines and research topics, mainly in the social sciences; and, on the other hand, insufficient involvement of different social actors. The more transcendent the consequences of a change to another resource base is, the more important a holistic vision will be that covers different aspects of social life, a variety of alternative implementation routes and a broad spectrum of research topics. Since this transition is a very complex process leading to fundamental changes in society, a diversity strategy is needed that broadens the path based on prevailing technology by integrating socio-ecological approaches and opening up to new ideas that may emerge from future challenges.

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