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An Analysis of Collaboration Networks in Bioenergy: Using the 'Bioen Program' to Evaluate Sugarcane Ethanol Biomass.

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Abstract:
This paper analyzes the network of scientific collaboration in sugarcane biomass. The impact of the FAPESP research program on bioenergy (BIOEN) is also analyzed, with a focus on the division of biomass and its subareas. Using detailed information from scientific articles in the subareas of Enzymatic hydrolysis, molecular markers, delignification, genotypes, enzymatic conversion, gene expression, nitrogen and photosynthesis, an evaluation of the international insertion of research and collaboration networks of Brazilian researchers is carried out. The methodologyconsists of the formation of clusters of publications indexed on the ISI Web of Science database. The selection of publications is guided by search queries based on keywords related to the subareas of biomass division. The software programs VantagePoint and Pajek are used to support the analysis of the information. The principle objective of the study is to identify the global incorporation of efforts to generate knowledge in sugarcane biomass carried out by BIOEN. Through an analysis of the indicators, it was possible to identify a number of factors related to scientific collaboration in the area of biomass, such as geographic distance, area with the greatest contribution in a determined field of study, and the dynamics of scientific collaboration between countries. An analysis of the biomass division of BIOEN, from a global perspective, showed little cooperation between Latin American countries. The results illustrate that Brazil generates the greatest amount of scientific knowledge regarding sugarcane biomass. However, when the subareas are analyzed separately, scientific publications from the US and China are also dominant.
Keywords:BIOEN-FAPESP; Bioenergy; Collaboration Networks;Knowledge; Sugarcane.

Uma Análise de Redes de Colaboração em Bioenergia: Usando o'Programa Bioen' para Avaliar aBiomassa de Etanol de Cana-de-Açúcar

Resumo:
Este artigoanalisa a rede de colaboração científica em biomassa de cana-de-açúcar. Também é analisado o impacto do programa de pesquisa da FAPESP em bioenergia (BIOEN), com foco na divisão da biomassa e suas subáreas. Usando informações detalhadas de artigos científicos nos temas das subáreas, sendo Hidrólise Enzimática, Marcadores Moleculares, Deslignificação, Genótipos, Conversão Enzimática, Expressão Gênica, Nitrogênio e Fotossíntese, é feita uma avaliação da inserção internacional das redes de pesquisa e colaboração de pesquisadores brasileiros. A metodologiaconsiste na formação de clusters de publicações indexadas na base de dados ISI Web of Science. A seleção das publicações é orientada por consultas de pesquisa baseadas em palavras-chave relacionadas às subáreas da divisão de biomassa do programa BIOEN. Os softwaresVantagePoint e Pajek são usados para analisar as redes e para tratamento dos dados. O objetivo principal do estudo é identificar a incorporação global dos esforços de geração de conhecimento em biomassa de cana desenvolvidos pelo BIOEN. Por meio da análise dos indicadores, foi possível identificar uma série de fatores que influenciam a colaboração científica na área de biomassa, como a distância geográfica, área com maior contribuição em determinada área de estudo, e a dinâmica da colaboração científica entre países. Uma análise da divisão de biomassa do BIOEN, de uma perspectiva global, mostrou pouca cooperação entre os países latino-americanos. Os resultados ilustram que o Brasil é o que mais gera conhecimento científico sobre a biomassa da cana-de-açúcar, porém, quando as subáreas são analisadas separadamente, as publicações científicas dos Estados Unidos e da China também são predominantes.
Palavras-Chave:BIOEN-FAPESP;Bioenergia; Redes de colaboração; Conhecimento; Cana-de-açúcar.

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1. Introduction

Energy transition to a more environmentally friendly economy demands discoveries and the combination of knowledge, the generation of new technological processes and devices, the combination of old and new technologies to build technical systems, and; an ongoing dialogue with socially organized groups and the state. Geels (2014) presents a formulation based on layers; each defines a specific field of scientific, technical, and social activities, intertwined by feedback. His approach is close to the idea of multilayers networks and complex systems (Kirman, 2010; Dickison, et. al., 2016).

Three elements are essential to the constitution of the multilayers networks with complex interactions: a) the complementarities between research fields (Bueno, et al., 2018); b) the possibilities of combination of technological devices and processes, connecting extended technological trajectories in junctions and derivates; (Kim,& Shin, 2018) and; c) the appropriate definition of social and environmental policies.

Winskel et al. (2014) define the idea learning pathways in energy fields showing the significant differences between the energy alternatives. The evolution of "the learning pathway" can be represented in a cartesian plane: a) to incremental to radical innovations; b) from distributed to concentrated systems.

The learning pathway is just a sub-space o the plan that points the extended trajectory. According to the authors, it is possible to see the transition of technologies. For instance, in the same research field, it is possible to represent a group of SME's doing incremental innovations in traditional fields and newly biotechnology firms exploring and exploiting new possibilities, like GM enzymes and synthetic biology. It means that decentralized efforts, with low coordination skills, can be the main feature of a learning pathway (or an expanded technological trajectory). Further, the sub-spaces turn towards more concentrated coordination and radical innovations (the application of radical enabling technologies, Ferrari, et al., 2019).

Applying the framework of "learning pathways" about technological systems' evolution, bioenergy is diverse – so decentralized and complex - entailing simultaneously radical and incremental innovations coming from different actors. It is possible to analyze various sub-trajectories whose evolution can be crucial to the diffusion of innovation (Silverberg,&Verspagen, 2005). Competing with other energy modular systems, like wind energy, bioenergy faces challenges from the heterogeneity of mills' performance, up to the criticisms based on the Research Social Inclusion approach (RSI), pointing to problems with work conditions, food supply issues, and business models (Postal, et al., 2020).

Why choose a too complicated energy field? Brazil had already done part of his job. One of the relevant components of the Brazilian transition to a greener energy matrix is bioenergy. Indeed, hydroelectricity had contributed in the last century to a greener energy matrix compared to other countries with higher energy per capita consumption. However, the increasing demand for energy in the previous 20 years was fulfilled by renewable energy (bioenergy, wind, and solar) and natural gas (IEA, 2019). The combination of economic interests to diversify sugar-cane based refineries (and soybean value-chain, in the case of biodiesel) with key innovations (flex-fuel cars) has consolidated this advanced fuel the Brazilian economy.

Was it the end of the game? Souza et al. (2018) add a critical component: the role of bioenergy in a climate-changing' world. To amplify the impacts of the diffusion of advanced and face the adverse effects of oil prices, the bioenergy system should have improvements from different layers: social measures, aiming to incentive the consume of ethanol and biodiesel; learning to reduce costs and promote productivity gains alongside the sugar-cane chain and., more importantly, generate innovations not only to improve productivity but to create new opportunities to transform mills in highly competitive biorefineries.

Brazil, and particularly research in the state of São Paulo - represented by 'Fapesp' (São Paulo State Research Foundation) - plays a prominent role in scientific research in many areas related to innovation and development in bioenergy fields. In São Paulo State, there is a geographical superposition of production, consumption of advanced fuels, and the country's scientific hotspot conditions (Mesquita, et al., 2019).

To better understand Brazil's bioenergy fieldthe paper looks to identify the main areas of research and collaborative networks involving researchers financed by FAPESP, comprising scientometrics to identify the main research fields and build the collaborative networks. The study contributes to answer the following research questions:

a) Is the Bioenergy Program –BIOEN– FAPESP an effort to incentive the complementarities of the bioenergy research areas and spur collaboration?

b) Did the BIOEN successfully coordinated research efforts during its duration, favoring research proximity that would be dispersed and far from the focus on innovation?

The paper is divided into six parts, including this introduction. The next section presents some features of the bioenergy sector worldwide, especially in Brazil. The Bioen program is characterized in the third part of the article. Section 4 shows the methodology and data used to construct and analyze research networks formed in the Bioen program. Section 5 presents and discusses the results, focusing on the role that Bioen funded research has on the global network of bioenergy research. The conclusion of the paper highlights the main results and presents some future research opportunities achieved.

2. Bioenergy Sector: AFrontier for Biotechnology Development

2.1. Global Perspective

Ethanol has become a global strategic fuel and a widespread alternative to climate change challenges: research areas involving carbon and energy balances and greenhouse gas emissions have gained particular relevance in recent years. The advantages of renewable sources include energy security, favorable environmental impacts, and job creation in industry and agriculture, as well as laying the foundations for the development of biotechnology, chemical engineering, materials engineering and related disciplines, all of which are of key importance to productive activities (Ribeiro, et al., 2010; Van Der Wiellen, 2013).

However, a key factor to understand technological diffusion is to have an international perspective of current markets and policies. For HLPE (2013, p.13) the biofuel markets (in ethanol) are policy-based with impressive results: "*in less than one decade, biofuel production has increased fivefold, from less than 20 billion litres/year in 2001 to over 100 billion litres/year in 2011*".

In this regard, the US Energy Policy (Energy Security and Policy Act of 2007) has kept its commitment to renewable fuels, fixing ambitious target values (136 billion liters/year, 52.6 billion from corn ethanol), with tax incentives, fixing fuel quality regulations, car fleet requirements, as well as providing credits for alternative fuel motors. One important policy decision is to determine a "blend wall" in E10, limiting the possibilities of ethanol from corn

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and simultaneously fixing targets for "advanced fuels" (World Bank, 2010; Babcock, &Pouliot,2014), comprising second generation and Brazilian ethanol, among others. The latter policy reveals the importance of sustainability criteria for the complete bioenergy and bioeconomy chains. The result, in the USA (also in Brazil), provides an incentive to expand the industry, with new entrants on the scene (Pereira, &Silveira, 2016). These new entrants, however, are facing high corn prices, higher construction costs and uncertainty about policy commitments to biofuels in the long run.

However, as pointed out by Just et al. (2006), Hall and Martin (2005) the building of the regulatory framework is key with regards to many important variables such as expenses on R&D, investments in new plants and the definition of expansion areas, such as those related to drop-in fuels, biorefineries and their design to produce new bio-based materials and chemicals such as bioplastics. In fact, there are many sources of uncertainties in terms of accomplishing a positive scenery:a) the possible change in energy policies in the main countries on the bioenergy scene, (e.g. the USA, Brazil and the EU), such as cuts in subsidies, fixation of new blend walls, to quote the most important policy measures; b) the emergence of new sources of energy, even those related to high levels of GHG emissions, such as pre-salt, shale gas (with a relative positive impact on the energy matrix), changing the energy prices (Babcock, 2013); c) the changing environment of public perception on biofuels, regarding land use and food security issues; d) the fierce competition between technological alternatives and its interplay with regulatory measures and sustainability criteria; e) the complex relation between new processes, new products, the building of new markets and the different market structures of the bioenergy chain.

2.2. Bioenergy in Brazil: Development, Opportunities and Hurdles

Since the 1970s, Brazil has developed impressive infrastructure in order to produce bioethanol. This infrastructure was built on the basis of a dual model of both sugar and ethanol production - the so-called "Brazilian model". One of Brazil's striking achievements is that the country dominates on the global stage with a significant share of renewable sources in its energy balance, estimated at 42.4% in 2012, with 15.4% coming from sugarcane as a raw material (Nagis-E, 2013; Salles-Filho, 2016). Brazil is the largest producer of sugarcane and the second biggest producer of ethanol. In 2009, ethanol use represented 47% of the fuel for light vehicles (a fleet of12 million cars). In the same year, 612 Mt of sugarcane were processed at 363 sugar mills. About 63% of the total amount of sugar cane processed by the industry is in the state of São Paulo, the most industrialized in the country.

Brazil is currently facing a serious crisis in the bioenergy sector, with a reduction in the number of mills in operation, a fall in the overall capacity to process biomass, a halt in Greenfield investments and a sharp reduction in the number of consumers that choose ethanol as a fuel. As a result, the system is coming under pressure due to several political and business reasons which have influenced the price of ethanol in relation to gasoline (MAPA, 2013).

Paradoxically, R&D research funds were not affected with the declared option to the Pre-salt and for the fact that fuel policies focused on inflation control with eyes in the next election, have kept mill owners far of introducing innovation processes (Pereira,&Silveira 2016; Gimenez, 2013). It is therefore possible to assume that research efforts and the results have not been affected by this 5-year period of crisis. In Brazil, the current model, based on the organization of productive activities and diffusion of technological innovation, is determined by cooperation agreements between sugarcane power plants and companies with commercial installations of 2G biofuels. Details on 2G biofuel installations in the country are presented in Table1 below. The information shows the unification between innovating projects carried out by new entrants and established companies (Bacovsky, 2013).

Table 1 - Brazil: 2nd Generation Biofuel Facilities

Organisation	GranBio	Amyris, Inc.	Amyris, Inc.	Amyris, Inc.	Amyris, Inc.	Petrobras	Raízen
Project Name	GranBio Plants	Amyris Sao Martinho	Amyris Paraiso	Amyris Biomin	Amyris Pilot & Demonstration Plant	Bioethanol second generation production	Costa Pinto Sugar Mills
Location	Alagoas	São Paulo	São Paulo	São Paulo	São Paulo	Rio de Janeiro	São Paulo
Technology	Biochemical Conversion	Biochemical Conversion	Biochemical Conversion	Biochemical Conversion	Biochemical Conversion	Biochemical Conversion	Biochemical Conversion
Raw Material	Sugarcane Bagasse and Straw;	Fermentable sugars; Sugarcane	Fermentable sugars; Sugarcane	Fermentable sugars; Sugarcane	Fermentable sugars; Sugarcane	Sugarcane Bagasse and Straw;	Sugarcane Bagasse and Straw;
Product	Ethanol	diesel-type hydrocarbons	diesel-type hydrocarbons	diesel-type hydrocarbons	diesel-type hydrocarbons	Ethanol	Ethanol
Output	80.000 t/year	n.d.	n.d.	n.d.	n.d.	4.500 t/year	40.000 t/year
Facility Type	Commercial	Commercial	Commercial	Commercial	Demonstration	Pilot	Commercial
Partners	Beta Renewables and Chemtex	Sao Martinho S/A	Paraiso Bioenergia S/A	Biomin GmBH; toll manufacturing	-	Blue Sugars	Novozymes
Start-Up	2014	2013	2012	2010	2009	2007	2014

Source: Bacovsky (2013).

By analyzing the projects in Table1, it can be seen that the diffusion of 2nd generation innovations in Brazilian industry tends to be guided more by the power plants productivity parameters and cost reduction. However, energy efficiency, emissions and life cycle impacts provoked by residues also continue to be relevant in the selection criteria. Thus, decisions to invest in 2nd generation technologies require multi-criteria models to evaluate effectiveness.

In Brazil, the extensive availability of raw materials that have a low opportunity cost and the high focus on development in the national biotechnology market, are factors that determine the current diffusion model of 2nd generation technologies. Such stylized facts wereare obtained in the techno-economic analyses carried out by Dias et al. (2012). These studies evaluate the effectiveness of the productive process in which biochemical technologies of conversion are integrated with the conventional ethanol plant.

As expected, the result when integration takes place is superior to that of when the plant is isolated. Similarly, Dias et al. (2013) evaluated the techno-economic results of the installation configurations that produce bioelectricity and ethanol. A change in the power plant's product mix does not alter the parameters that show the isolated progress of 2G technologies obtained in laboratory experiments. However, the increase in opportunity cost of biomass (bagasse) produces systematic effects that strengthen the capacity of technological development to gather raw materials, for example, straw and tops, more efficiently.

Techno-economic evaluations make it possible to compare the effectiveness of different productive configurations of 2G biofuels and provide a basis to analyze alternatives for the commodity chain. In Brazil, regarding the dominant model of diffusing 2G technologies, the parameters used in simulations are restricted to the biochemical conversion path, the biomass of sugarcane and to the ethanol-electricity product mix.

3. Fapesp Bioenergy Research Program – Bioen Program

In 2008, FAPESP - São Paulo Research Foundation (the most important research fund in Brazil), launched the BIOEN program, which is the motivation behind the research presented in this paper. The BIOEN program inspired collaboration among the largest universities in Brazil involved in studies on bioenergy. This effect reflects the significant scope of this project. One example is the creation of the São Paulo Bioenergy Research Center (CPPB), which is a union of the State University of Campinas (UNICAMP), the University of São Paulo (USP), and São Paulo State University (UNESP). Together, these institutions now provide a joint doctorate in bioenergy that includes five areas of research (the same areas included in the BIOEN program).

It is also important to note the efforts toward cellulosic ethanol research, which include collaborations between Brazil and Europe. In 2009, the National Laboratory for Bioethanol Science and Technology (CTBE), together with FAPESP (2009), announced that a group of member researchers of the BIOEN program had established scientific collaboration projects with Cambridge University and the University of York in England. The focus was on the cooperation between BIOEN researchers and those from English universities on joint projects on the topic of bioenergy under the Seventh Framework Programme (FAPESP, 2019).

The project is ambitious, and in a short amount of time, Brazil was able to understand and alter the structure of the cell wall of sugarcane plants. Researchers also discovered enzymes and microorganisms capable of converting biomass into energy. In this ambitious series of events, BIOEN's objectives were to overcome technological barriers and to further increase productivity in the production of first-generation ethanol, which occurs through the fermentation of sucrose and uses a third of the sugarcane biomass. Another objective was to participate in the international race for second-generation ethanol, which is produced using cellulose.

The challenge for researchers in the program has been to connect the theoretical science to the applied science and create a way to make this knowledge available for industrial use.

4. Materials and Methods

The mainsample used for the analysis in this study consists of a collection of articles available on the ResearchIDof BIOEN-FAPESP at the Web of Science plataform. Based on this set of publications, the article created networks that captures Bioenergy research efforts and structure in Brazil and abroad. To this end, after the ResearchID sample was analyzed, the Digital object identifier'(DOI) codes from the articles were selected in order to download the same data, but with cited reference fields, which allows for the creation of a citation, collaboration and others network. With the aid of the R statistical software package, the paper calculated measures of centrality and designed the networks analysed in the results.

Regarding the measures of centrality, the degree is the extent or measurement of information. Historically, degree centrality is conceptually simpler, and is defined as the number of connections occurring around a node (i.e., the number of connections a node possesses). The degree can be interpreted in terms of immediate risk of a node for catching whatever is flowing through the network (such as a virus, or some information). In the case of a directed network (where connections have direction), we tend to define two distinct measures of degree centrality: indegree and outdegree. Thus, indegree is a count of the number of connections directed to the node, and outdegree is the number of connections that the node directs to others.

When ties are associated with a certain aspect, such as friendship or collaboration, indegree is frequently interpreted as a form of popularity, and outdegree is interpreted as social (Souza, et al., 2015). This number represents the measurement of "intermediation." It is a centrality measure of a vertex within a graph (there is also the idea of betweenness of ends, which is not the topic of discussion here). Betweenness centrality quantifies the number of times that a node acts as a point along the shortest path between two other nodes. It was first introduced by Linton Freeman as a measurement for quantifying the control of a human being in terms of communication with other human beings in a social network.

In order to focus the analysis on the bioenergy research on biomass, the present study divided this field of knowledge in 9 blocks or subareas of research: Enzymatic hydrolysis, molecular markers, delignification, genotypes, enzymatic conversion, genetic transcription, nitrogen and photosynthesis. Based on these subareas, key words were chosen for the search into the statistics on the areas of study. The searches were performed using the Web of Science database, which was gathered with the DOI code of the papers. The VantagePoint software was also used as an aid to analyze the information and design clusters. Ucinet and the R Statistical Package were used to model the networks. Using the key words, 2,977 papers were recovered. The scientific publications were mapped at the international level.

All of the searches were performed in the "topic" field, which included the article's title, abstract, keywords from the author(s), and the "keyword plus" option. The search for information was specific to sugarcane. The search was made possible with the help of Boolean data types, such as AND. This operator creates an exact search for related terms within a single document (for example, delignification AND sugarcane). The Web of Science results displayed the two topics that are in the document. Proximity operators were also used. They allow for semantic variations of a term, and also aid in the search for words in both the plural and singular forms. The analyses were limited to scientific articles. Other documents, such as book chapters and abstracts, were excluded from the ISI Web of Science database search.

5. Results and Discussion

Identifying the country of the first author of 440 articles, Brazil presented 353 papers, followed by the USA with 32, and surprisingly, South Korea, with 12 and Portugal with 9. Almost 20 countries are directly related to the BIOEN program by co-authorship in publishing papers. The USA and South Korea's contributions of first-author studies represent a significant portion of the BIOEN knowledge network. Table2 represents the 10 most frequently cited articles in the BIOEN network. The degree is a unit to measure citations among authors in the network. Outside citations are those in which the authors cite articles from the network but not within the article. The most frequently cited article possesses a degree of 13, which means that the article was cited 13 times in articles within the network. It has been cited a total of 39 times, which means it was mentioned in a total of 26 outside citations.

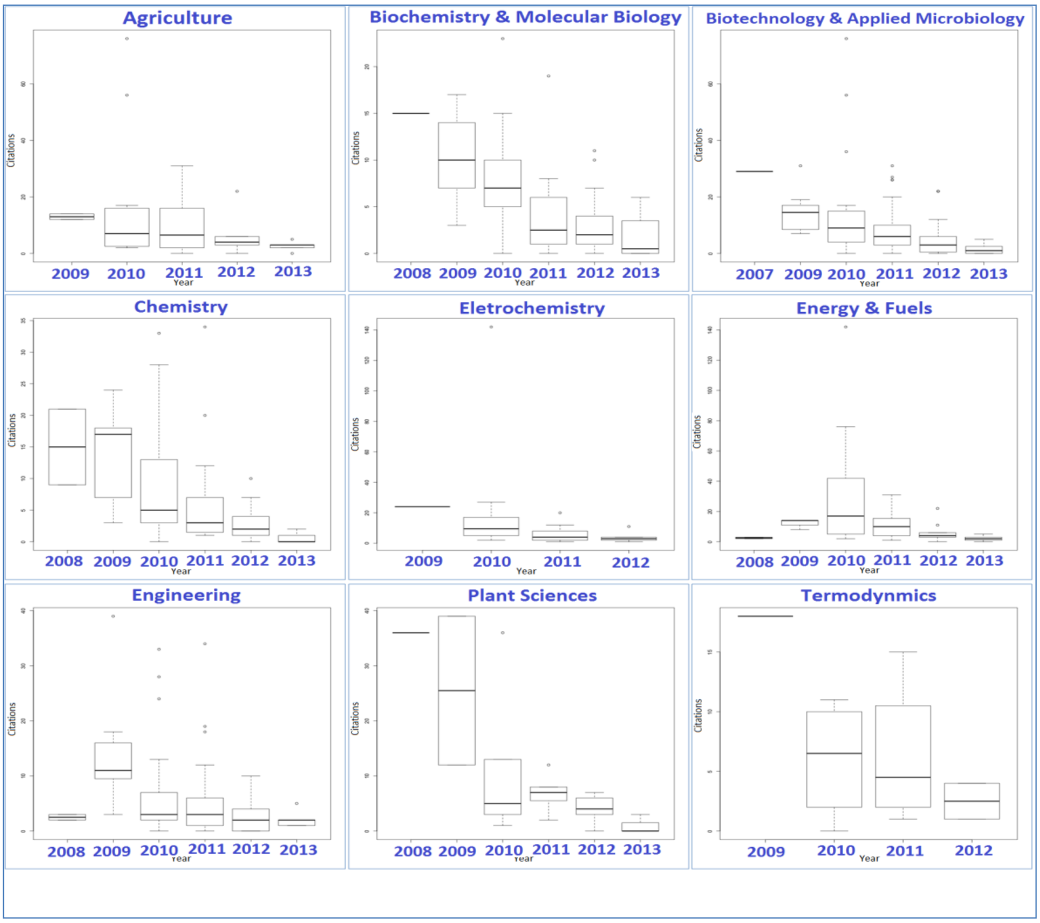
Table 2 -The 10 most frequently cited articles in the BIOEN network

DOI	Citation	Degree – citation within the authors of the network	Outside citation: not within the network
10.1016/j.cherd.2009.06.020	39	13	26
10.1016/j.jelechem.2010.01.026	19	10	9
10.1016/j.chemphyslip.2008.09.006	13	8	5
10.1016/j.biortech.2011.09.120	22	8	14
10.1016/j.pep.2009.06.014	15	7	8
10.1016/j.jfoodeng.2009.05.009	11	7	4
10.1016/j.chemphyslip.2009.05.004	17	7	10
10.1016/j.biortech.2009.11.067	56	7	49
10.1039/c002574g	13	6	7
10.1016/j.energy.2010.09.024	15	6	9

Source: Authors' research results by Researcher ID-BIOEN, Web of Science (2020).

Out of the 440 articles, the citations totaled 3.057 over all of the years analyzed .The citations were analyzed by area and by year, between 2007 and 2013. The citations by area and year are outlined in Figure 1 below. Science changes at its own pace. As the previous figure demonstrates, there is a natural decline in citations, based on the logic that the newer an article is, the less frequently it is cited. This represents new knowledge, or knowledge that is not yet widespread in the scientific community.

Figure 1 - Citations by research area and year - 2007-2013



Source: Authors' research results by Researcher ID-BIOEN, Web of Science (2020).

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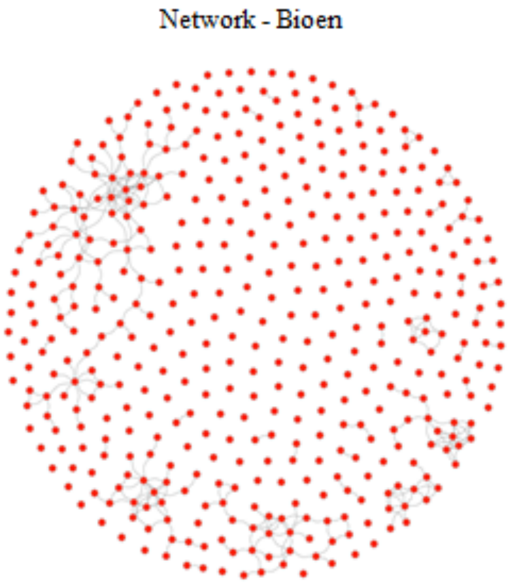
Another important factor is that some articles are already frequently cited − those that are represented in the following figure by dots separated by citation measure. This fact shows that, even with the natural process during which articles begin to be cited, some articles already possess a high rate of citation and have an impact on the network of knowledge. However, Figure 2, below, reveals an expressive number of isolates in the network, suggestsing that the methodology should be applied to a broader database. BIOEN is too recent a program to establish a pattern of connections that reveals emergent areas.

Figure 2 - General web of scientific collaboration of the ResearcherID from BIOEN - 2007-2013



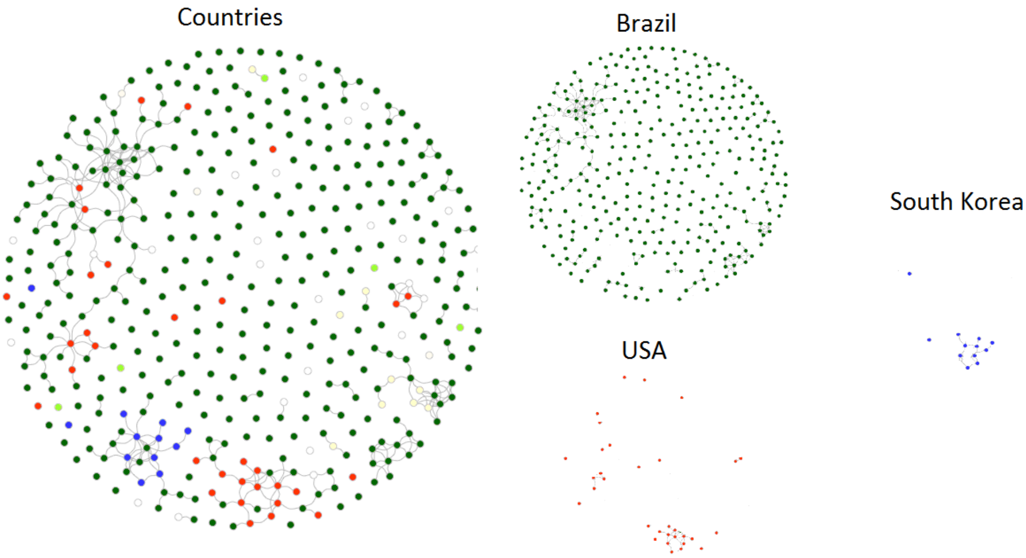
The web has almost no connections among its authors.

The arrows show the few collaborations within the web/network.

Source: Authors' research results by Researcher ID-BIOEN, Web of Science (2020).

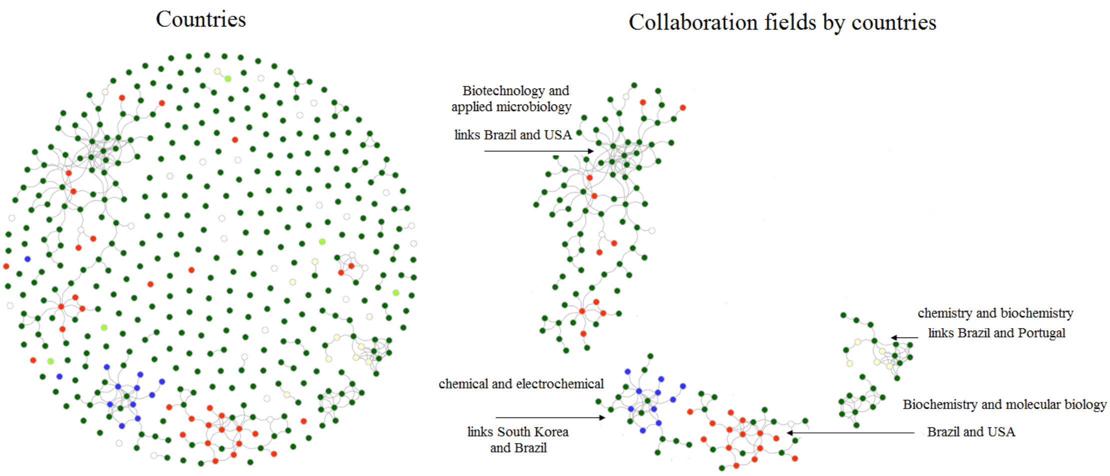
Network indicators confirm the observations made above. The measure of degree is 0.001574. The index of BETWEENNESS is 0.391. In the ResearcherID archives, the counties which stand out for their collaborations with BIOEN are the USA and South Korea. The image below shows the complete network and the individual scientific contributions among Brazil, the US, and South Korea.

Figure 3 - Networks by Country



Source: Authors' research results by Researcher ID-BIOEN, Web of Science (2020).

Figure 4 - Networks and Research Areas



Source: Authors' research results by Researcher ID-BIOEN, Web of Science (2020).

In Figure 4, on analyzing the network, we can identify how synergy occurs in the BIOEN articles by country and area of research. The blue nodes represent South Korea. It is important to note how South Korea dominates this node, and vertices much less frequently connect that Brazil. The same network as those above was analyzed, but without the nodes that were are not connected to any others. The area of research and country connected to each node were analyzed. The results, displayed in the graph of the network, show how the scientific areas of research, such as chemistry and biochemistry, are connected.

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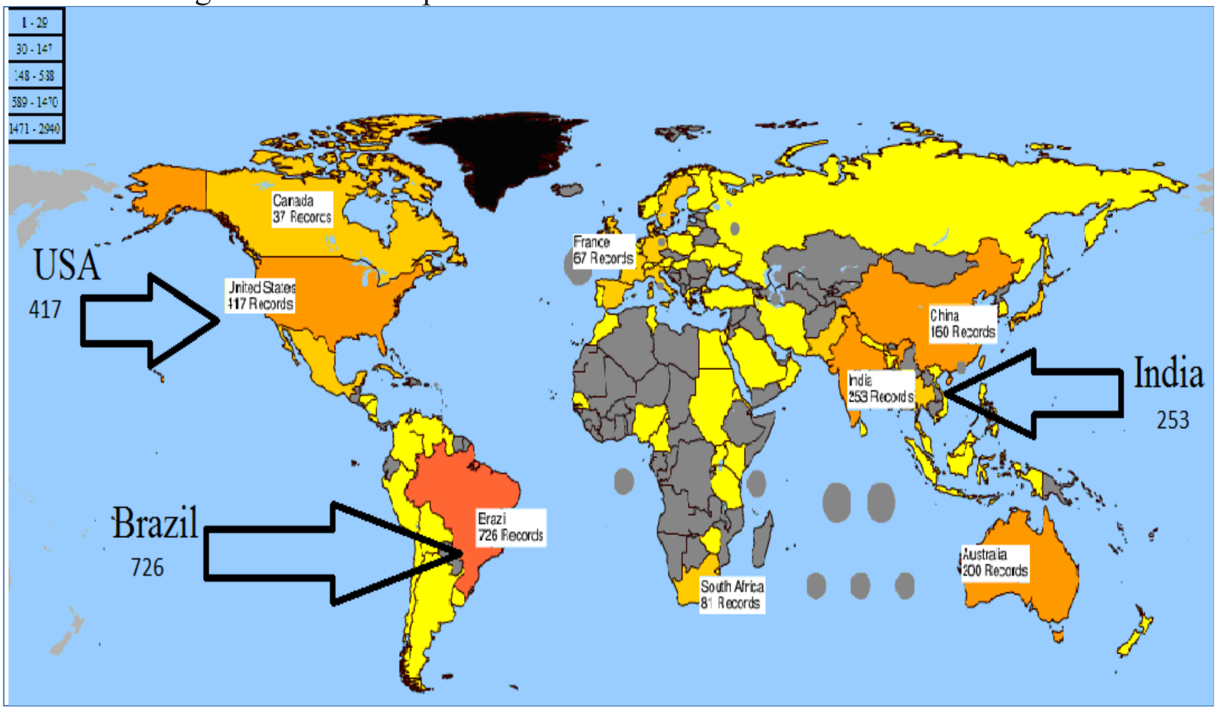
Regarding the characterization of Sugarcane Biomass research in the world, the first analysis identifies the leading countries in the production of knowledge in sugarcane biomass. The map below shows their distribution. As Figure 5 shows, Brazil possesses the world's highest number of scientific publications on biomass, with 726 scientific article publications. The United States came in second with 417, and India published 253.

Figure 5 - Articles published on biomass between 1975 and 2013.



Note: Script supplied by The VantagePoint, Word Map®.
Source: Authors' research results (2020).

Table 3: The 10 most frequently cited articles in the BIOEN network

Country	*Papers – Ranking main*	*Ranking*	*Percentage of distribution*
Brazil	726	1º	24,39%
USA	417	2º	14,0%
Índia	253	3º	8,5%
Australia	200	4º	6,7%
China	160	5º	5,4%
South Africa	87	6º	2,9%
France	67	7º	2,3%
Canadá	37	8º	1,2%
Brazil	726	1º	24,39%
USA	417	2º	14,0%

Source: Source: Authors' research results (2020).

The main countries represent 65.4% of total publications in biomass of sugarcane. The other less notable countries represent 1,030 scientific articles. When we analyzed the subareas of study involved in sugarcane biomass research separately, the results became even clearer. The results are shown in the Table 4, below.We can see that, when analyzed separately, Brazil does not maintain its dominance over all of the technologies involved in the sugarcane biomass production process. The differences between the leader and second place are slight in some areas. This factor proves to be of importance when one considers that it could be the basis for better allocation of resources in Brazilian research.

In addition, if one area of research is well established and another is not, would there not be a decreased possibility of innovation and technological application? Another important point to consider is that, if Brazil dominated all of the technological areas of research that are involved in sugarcane biomass, the country's chances of innovation and application would certainly be greater. In the total set of publications on biomass, Brazil is the leader in the production of knowledge; however, when analyzed separately, some areas are dominated by other countries. One example is the area of molecular markers, the area in which the dominance of scientific production belongs to the United States, followed by Australia.

Table 4 - Sugarcane biomass, Sub-Area: Most Significant Results in Publication

BiomassSubarea	Country with the most Publications(Decreasing Order)	Author with the most Publications	Institution with the most Publications	Most Frequently Cited Article
EnzymaticHydrolysis	Brazil (74); India (35); USA (19); Australia; (11); China (11)	Milagres, A. M. F. (9)	(19) Universityof São Paulo	Effects of irrigation-induced salinity and sodicity on soil microbial activity (143)
Molecular Markers	Brazil (17); Australia (15); France (14); USA (13); Índia (12)	Glaszmann J.C. (10)	Commonwealth Scientific Industrial research organization CSIRO (12)	Microsatellite markers from sugarcane (saccharumspp) ESTS cross transferable to erianthus (204)
Delignification	Brazil (209); USA (95); China (76); India (59); Cuba (29)	Martin, Carlos (22)	(77) Universityof São Paulo	Hemicellulosebioconversion (510)
Genotypes	USA (120); Brazil (88); Índia (77); Australia (62); Pakistan (45)	Glaz, B. (31)	United States Department of Agriculture (USDA) (63)	Microsatellite markers from sugarcane (SaccharumSPP) ESTs cross transferable to erianthus and sorghum (204)
EnzymaticConversion	Brazil (28); USA (14); Índia (13); Japan (6); Sweden (5)	Milagres, A. M. F. (8)	(13) Universityof São Paulo	Hemicellulosebioconversion (510)
Geneticexpression	China (12); USA (11); Canada (4); England (4); France (3)	Hayashi M. (4)	Chineseacademyofsciences (3)	Control by estrogen of genetic transcription and translation (270)
Nitrogen	Brazil (310); Índia (152); USA (134); Australia (108); Japan (46)	Trivelin, P.C.O. (34)	(100) Universityof São Paulo	A new acid-tolerant nitrogen-fixing bacterium associated with sugarcane (274)
Photosynthesis	USA (46); Brasil (38); Australia (23); South Africa (14); Japan (11)	Ribeiro, R. V. (9)	United States Department of Agriculture (USDA) (19)	Stomatal conductance and photosynthesis vary linearly with plant hydraulic conductance in ponderosa pine (257)
Pestcontrol	Brazil (63); USA (58); Australia (23) South Africa (14); France (13)	Reagan T. E. (8)	(21) Universityof São Paulo	Field-Evolved Insect Resistance to Bt Crops: Definition, Theory, and Data (125)

Source: Authors' research results (2020).

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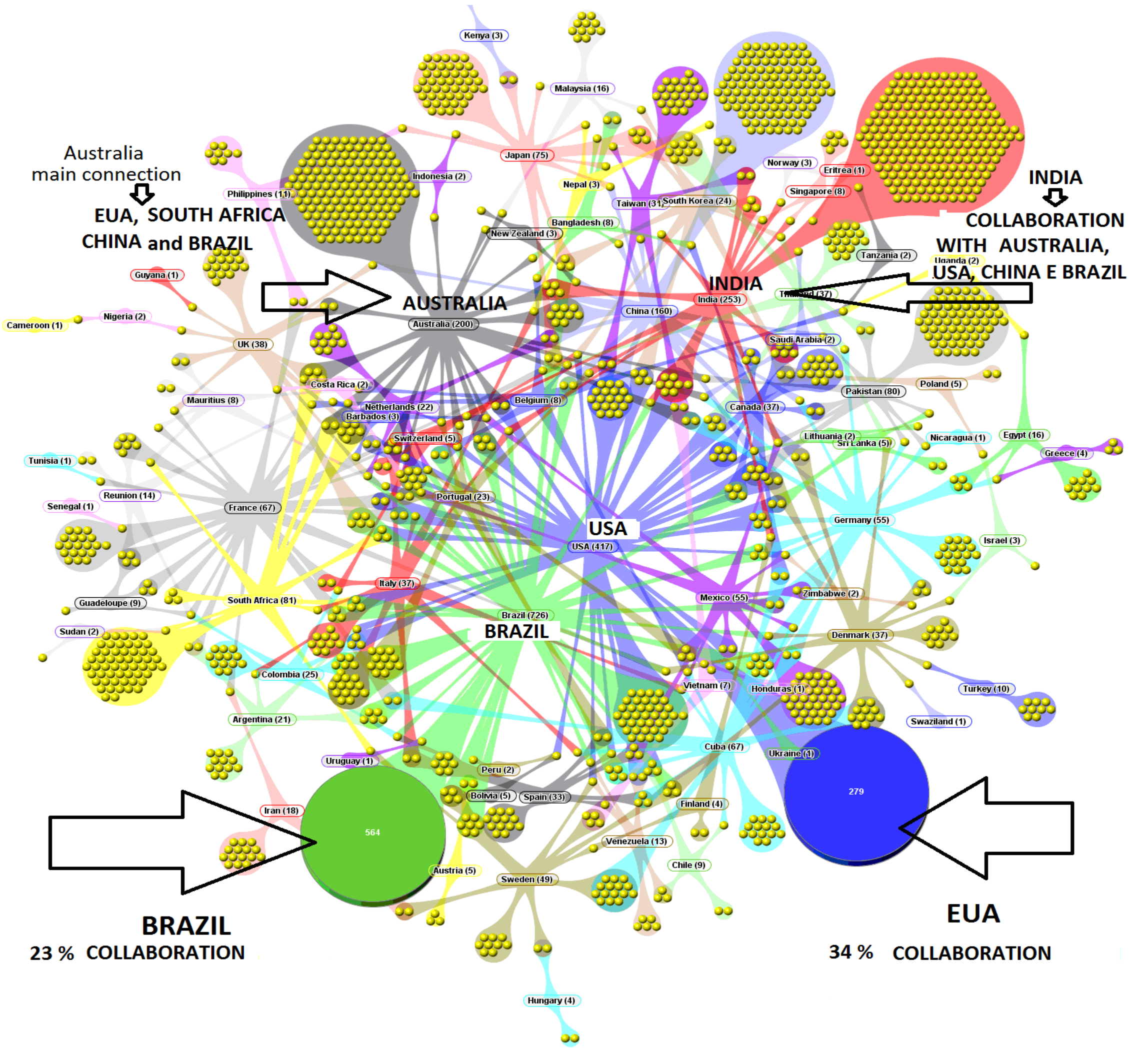
Considering the total number of publications on sugarcane ethanol, Brazil in the leader in the production of knowledge (see table 3). When the analysis was carried out separately, however, certain areas are shown to be dominated by other countries. At this point, we would like to note the importance of individual analysis by area of research, which makes it easier to see the phenomena of each country's contribution of scientific knowledge separately. In the subareas of genotypes in sugar cane and photosynthesis, scientific production is dominated by the United States. Another important point to note is with regards to the subarea of genetic expression, which is dominated by China and Chinese institutions. Brazil is not in the top five countries in this area of knowledge.

Interestingly, when results of the analysis are performed separately, it more faithfully shows the performance of each area, article, country, and institution. For example, the most frequently cited article is "Hemicellulose bioconversion", with 510 citations. It appears as the article that contributed the most to the development of science in the subareas of delignification and enzyme conversion. Certain subareas, such as that of pest and disease control and molecular markers show slight differences in the number of publications. Brazil appears to be slightly ahead of the United States. This factor proves to be of importance when one considers that it could be the basis for better allocation of resources in Brazilian research.

In the subarea of delignification, researcher Carlos Martin appears most frequently in the publications, and the dominant institution is the University of São Paulo (USP). This occurs because synergy in science is often intrinsic. In this case, researcher works at an has an institution in Cuba, the Department of Chemistry and Chemical Engineering at the University of Matanzas and his scientific collaboration is with researchers from USP; for this reason, he is grouped together with other researchers and appears more frequently. Global collaboration on research subareas is another determining factor in the development of research. Fig. 6 below shows the collaboration interactions in studies on biomass around the world. Here, the importance of the result is highlighted. The countries that are collaborating with Brazil are progressing on the knowledge frontier, as is the case of India, the USA and Australia. We can see in Fig.6 how this synergy occurs.

Figure 6 - Collaboration network among countries studying biomass subareas



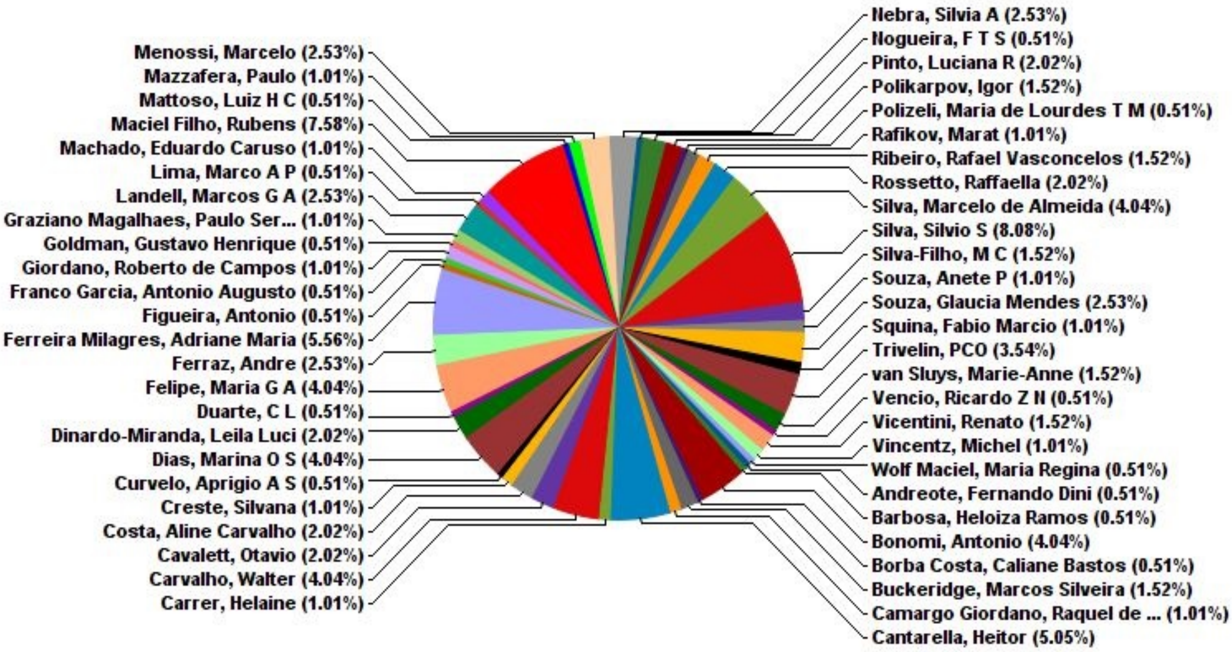
Note: Script supplied by The VantagePoint, Aduna Cluster Map®.
Source: Authors' research results, adaptade Bueno (2016).

In the cluster, Brazil country's collaboration with researchers of other countries is represented by green lines, and the can be seen in a follow that is similar to that of other large synergies, such as the USA (blue) and India (blue). It is important to note that Brazil's involvement is not only as the leader in the production of knowledge on sugarcane biomass, but also in collaboration relationships and complementarity with other countries, actions which are paths toward development. Brazil presents a 23% rate of collaboration on the international network, the principal partner being the USA, a country that also collaborates internationally, with 34% of collaboration being with Brazilian researchers.

There are a total of 7485 authors, of 20 different nationalities in the global network.To analyze Brazil's contribution and the performance of Fapesp's bioenergy program - Bioen - we used VantagePoint™, and for the development of the networks, we used UCINET. The project research leaders or coordinators were chosen, as these researchers are most likely to be those involved in scientific productivity. The selection resulted in a list of 107 researchers.

From the selected list (the 107 Bioen researchers), we located 51 researchers studying productivity in the global network. The chart below shows their contribution in percent on the global network of sugarcane biomass knowledge.

Figure 7 - Most Important Authors in the Global research on biomass from sugarcane. Papers 2008-2013

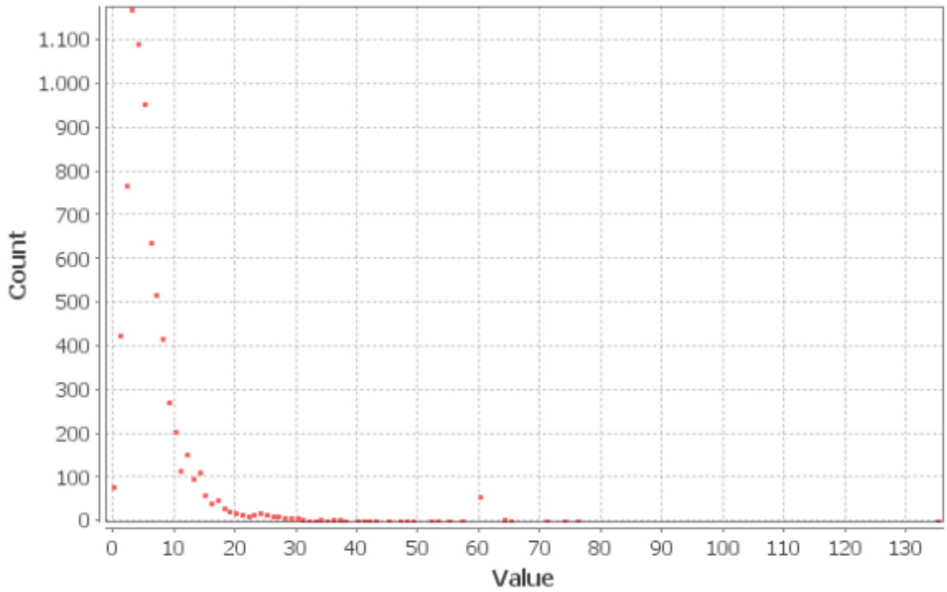


Note: Script supplied by The VantagePoint, Aduna Cluster Map®.
Source: Authors' research results (2020).

Here it is possible to see the importance of the Bioen program. This is because, from a little over 400 researchers, we chose 107, 51 of which are involved in the global network. It is important to remember that this is a new research program (launched in 2008) and is based on documents indexed on the Web of Science, which is considered a reference database for the frontier of scientific knowledge.

The publications are organized by year. It is important to point out the significant growth seen when we analyzed the publications by the BIOEN researchers who have been studying productivity since 2001. This increase was most significant after the FAPESP bioenergy program was implemented. Citations can be analyzed using the degree, a measurement of information defined as the number of incident calls per node (for example, the number of calls that one node possesses. The degree can be interpreted in terms of immediate risk of a node for catching whatever is flowing through the network (such as a virus, or some information). The graph below shows Bioen's degree in the global biomass network.

Figure 8 - Degree - Bioen in global network biomass sugarcane ethanol

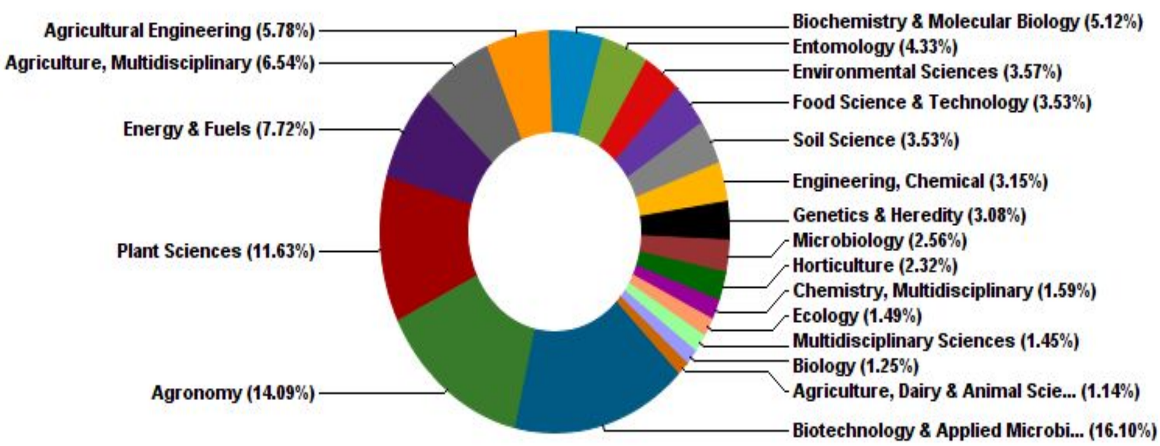


Source: Authors' research results (2020).

For this case, we used the total degree, in other words, the sum of indegrees and outdegrees (the number of articles that cite and are also cited). The result shows that the majority of articles have few citations, while the minority, which go from 0 to 300 have a high degree, with around 20 to 50 citations.

Under these circumstances, the areas of knowledge are key. Brazil's contribution through Bioen could represent the direction in which science is going, as well as offering a foundation in order to understand scientific structure based on knowledge. To understand the dynamic, the chart below shows the distribution.

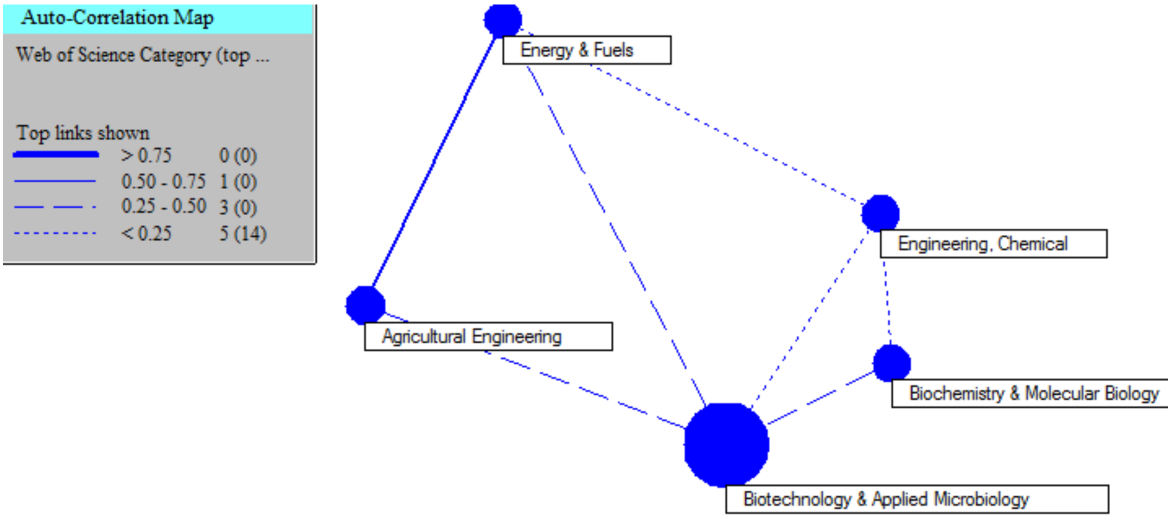
Figure 9 - Knowledge areas– Bioen



Note: Script supplied by The VantagePoint, Aduna Cluster Map®.

Source: Authors' research results (2020).

Figure 10 - Knowledge areas – World



Note: Script supplied by The VantagePoint, Aduna Cluster Map®.
Source: Authors' research results (2020).

In terms of scientific knowledge, the largest contribution is in the area of applied biotechnology and microbiology, at 16.10%, followed by agriculture at 14.09%. These figures show how the program is strongly progressing on the frontier of scientific and technological knowledge.

6. Conclusions or Final Considerations

The results identified a series of factors that influence scientific collaboration in the biomass area, such as geographical distance, the area with the greatest contribution in a given study area, and the dynamics of scientific collaboration between countries. The results showed that Brazil would be the country that generates the most scientific knowledge about sugar cane biomass, and BIOEN researchers as central to the global knowledge network. However, when the subareas are analyzed separately, scientific publications from the United States and China are also prevalent.

Through the analysis of the indicators presented herein, particular factors that seem to influence scientific collaboration in the biomass industry are observed. This area makes the greatest contribution by given field of study, as well as the greatest dynamic in terms of scientific collaboration among different countries. From the results exposed through a global perspective achieved when biomass was distinguished from the BIOEN program, one of the most discouraging findings is the low amount of current cooperation among Latin American countries involved in the biomass industry. This region is rich in biologically diverse resources as has the potential to explore this incredible biodiversity which can be used for research and innovation; efforts must, however, be made to form policies on science and technology that would make it possible for countries to transfer technology.

Through the indicators of production, we were able to verify the importance of Brazil as the most significant producer of scientific knowledge in the biomass industry in terms of studies on sugarcane to be used for energy production. However, when the subareas are analyzed separately, the results favor both the USA and Brazil, each of which dominates a different area of the sugarcane biomass industry. Another factor to note is the connection between Brazil and other developed countries, particularly the USA and India.

Regarding the results from Bioen, it is possible that the program represents the knowledge frontier of the future of science and technology, as the majority of investments are made in the areas of biotechnology. To do this, however, it is important to observe the distribution of investments by area that involves biomass. As shown here, the subarea of genetic expression, in which China dominates the publications from this query, Brazil does not appear to be among the top five in this area. Photosynthesis is one area that must also be better developed.

Brazil has a significant chance of becoming an economy based on low carbon energy, and sugar would cease to be a product and become a subproduct of the sugarcane-alcohol sector. Thus, understanding the status of the production of scientific knowledge and technology and the networks that complement these activities, becomes the key to identifying and dominating these changes in technology. Finally, this study is an attempt to add to the discussion on Brazil's scientific and technological contributions. These contributions were evaluated using the BIOEN program on biomass, and more specifically area of second-generation ethanol.

For Brazil to secure its leadership position, both in the area of science and in ethanol production, there must be investment in projects in order to show that the technology developed in the laboratory also works on a larger scale.

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