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TRACKING BIOFUELS-INNOVATION RELATIONSHIP THROUGH SCIENTIFIC AND TECHNOLOGICAL ADVANCES

Corina MARINESCU
Bucharest University of Economic Studies, Bucharest, Romania
corina.marinescu@man.ase.ro

Claudiu CICEA
Bucharest University of Economic Studies, Bucharest, Romania
claudiu.cicea@man.ase.ro

Sofia Elena COLESCA
Bucharest University of Economic Studies, Bucharest, Romania
sofia.colesca@man.ase.ro

Abstract
The aim of the paper is to establish the relationship between two concepts, biofuels and innovation, and to highlight progress by referring to scientific research and technological advances. Innovation is a key element in the development and deployment of biofuels so, the first step in describing their relationship is to studythe main flow of the literature since they both appeared treated simultaneously. This step assumes analyzing the selected papers, highlighting their impact in time and then developing a co-occurrence analysis of the keywords. The utility and the relevance in using a co-occurrence analysis lays in its capability of revealing period specific research topics. The second step involves the analysis of patents evolution in the field of biofuels, as they have an increasingly role in encouraging innovation.Thus, the authors use the patents analysis as a way of analyzing technological advances. Finally, the findings reveal that both recent scientific and technological advancements are related mainly to biogas, bioethanol and bioeconomy, while sustainable development and ethanol dominate the beginnings of the research on this area.
Keywords:biofuels, co-occurrence, innovation, keywords map, patents.

1. INTRODUCTION

This paper focuses on connecting biofuels with innovation, as two concepts treated in the vast literature of the last years. Thus it aims tracing biofuels-innovation relation from a scientific point of view by studying research published by the most influential journals and publishers. The scientific research is almost always related to technological advancements within the field of biofuels as a key element of innovation, so the focus falls in the last part of the paper on patents registered in this area.Technology development isn't the only one describing and supporting innovation within the biofuel field. According to IRENA(2016), regulatory frameworks and business models are also vital in speeding up biofuels development in particular and renewable energy in general. Other authors stress out the importance of public policies (Zamfir, Colesca & Corbos, 2015) or financial support from structural funds (Štreimikienė, 2016).

There are previous papers focusing on a similar relationship (Cicea et al., 2019) or just studying the biofuel research (Yaoyang& Boeing, 2013) to highlight the exceptional growth of scientific knowledge in this field. However, the novelty of this analysis consists both in revealing trends in biofuel-innovation research and the impact of this research. By reviewing the science behind biofuels-innovation, one is expected to obtain valuable information on how things are moving in this field capable to answer global challenges.

2. LITERATURE REVIEW

The present paper uses bibliometric methods for analyzing biofuels-innovation relationship in terms of science and technological advancements. In the literature there are similar works aiming to analyze emerging topics. For instance, Ma et al. (2018) approach the microalga-derived biodieselemphasizing the crucial role in the sustainable development of biodiesel and the expanding research outputs on this topic. Literature on biofuels has also been studied by De Carvalho et al. (2015) on a period of twelve years till 2010, revealing that the greatest interest of researchers as oriented towards alternative energy sources, substitute fuels and biomass and their possible impacts on agriculture, performance and gas emissions.

If separating biofuels on categories, biodiesel is by far the most studied type of biofuel. As Zhang et al. (2018) show in their bibliometric analysis on biodiesel, that microalgae, Jatropha curcas, vegetable oil and waste cooking oil are the most general raw materials for biodiesel production. Yu and Meng (2018) develop their analysis in order to reveal the macrostate of the development of biomass field, while Wang et al. (2013) focus on biogas, by identifying global research trends related to the anaerobic digestion for methane production.

The utility of using bibliometrics stand in its capacity, as a statistical tool, of providing information about knowledge within a field, of mapping and clustering items of interest in order to reveal insights related to trends of topics in a specific area. As widely explained in a previous paper (Marinescu & Cicea, 2018) there are several types of bibliometric analyses used to explore contents of the vast literature. The next section of the paper describes the steps involved in conducting the analysis.

3. METHODOLOGY

For paper selection, the Scopus database was chosen, as it claims to be an international-recognized and widely-used platform documents indexation. By using its search options, one can receive access to papers from a great variety of research areas, and to thousands of publications from well-known publishers, such as Reed Elsevier and Taylor and Francis.

Within this research papers, the next five steps were followed, in order to conduct the analysis.

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1) The first step assumed searching for the two main keywords of the analysis, meaning biofuels and innovation. The search was conducted in March 2019 and used the “Article title, abstract, keywords” field from those available on the platform. The search returned 755 papers.

2) The second step presumed selecting only papers written in English. There were 731 documents with this characteristic.

3) The third step envisaged the publication year of the selected papers. There were 16 papers reported as being published in 2019 and one paper in 1996 and also one in 2000. So, for a continuous period of time within the analysis, the 1996 and 2000 years were excluded. The 2019 year with the associated papers, was also excluded, as the authors considered it not relevant for the reason of not being a full year. After refining the selection as explained, 714 documents remained in the selection.

4) The next step refers to selecting only papers belonging to the main stream of publications, namely articles, reviews, conference papers and conference reviews. By applying this new condition, 583 papers matched the selection.

5) The last step envisaged the subject area of the papers. Areas with less than 30 reported papers were excluded. After this adjustment, 478 papers remained within the selection.

With all 478 papers, the following analyses were developed:

a) An analysis of the selected papers (the number of papers by year and by country, top 10 authors and institutions with contributions related to the subject of biofuel-innovation,papers distribution on journals and conference volumes);
b) An analysis for the received citations (citations received by yearand top 10 most cited scientific papers) which aim is to reveal the impact of the selected papers;
c) An analysis of the keywords (including occurrence, co-occurrence and links between them and keywords maps).
d) An analysis of patents results provided by the platform.

4. RESULTS AND DISCUSSION

4.1. Analysis of selected papers

The distribution of the 478 selected papers can be found in figure 1, a graphical representation which points out to a difficult start of the research treating biofuel-innovation subject that needed more than three years to “take-off”. The figure also reveals an increasing trend, with ups and downs between 2008 and 2018, and a peak of 53 manuscripts in 2017.

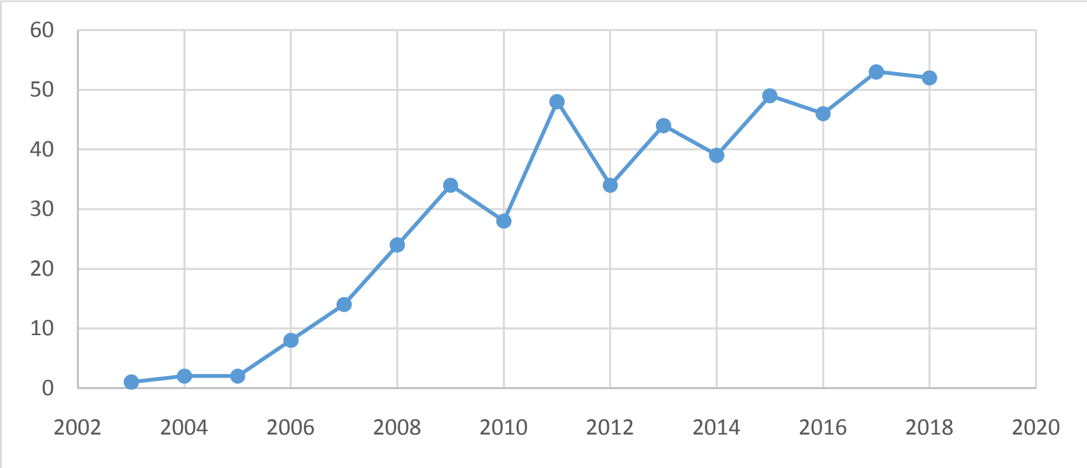

FIGURE 1-PAPERS BY YEAR
Source: authors based on Scopus (2019a)

Figure 1 also shows that the last five years account solely for 50% of all published papers on this subjects, while the other half is distributed from 2003 to 2013.

According to Figure 2, there are three countries, United States, United Kingdom and Netherlands that account for more than a half of papers published in the field of biofuel-innovation. As shown in a previous paper (Marinescu & Cicea, 2018), United States ranks first when it comes to biofuel consumption in the world. United Kingdom places itself among largest consumers of biodiesel, while Netherlands occupies a similar position but as ethanol consumer. The next three countries, Brazil, Italy and Germany are the leading countries in South America and respectively Europe that have the largest installed capacities for producing biogas (IRENA, 2018a). Therefore, there is indeed a connection between advanced scientific research developed by authors and researchers in those countriesand there position as leading producers and consumers.

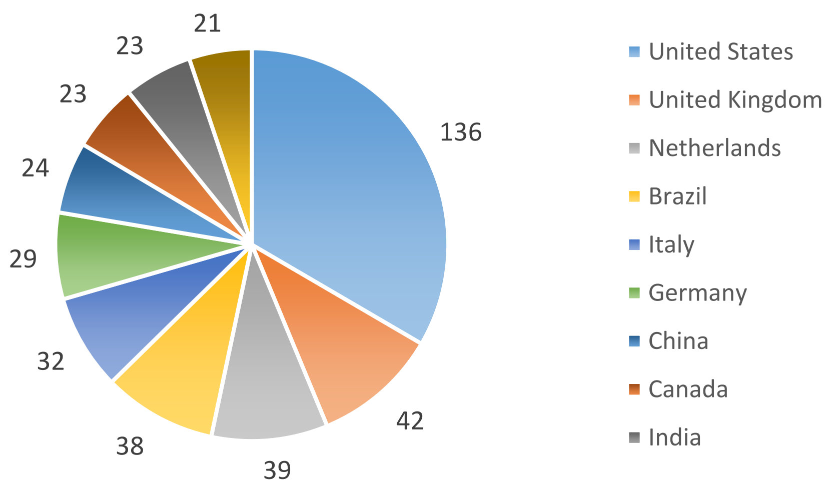

FIGURE 2 - PAPERS COUNT BY COUNTRY
Source: authors after Scopus (2019a)

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TABLE 1 - TOP 10 AUTHORS AND INSTITUTIONS WITH CONTRIBUTIONS RELATED TO THE SUBJECT

Authors	Contributions	Top 10	Contributions	Institutions
Levidow, L.	5	1	8	Utrecht University
Kafarov, V.	4	2	8	University of California, Berkeley
Caniëls, M.C.J.	3	3	8	LundsUniversitet
Chandra, R.	3	4	8	Technische Universiteit Eindhoven
Chiaramonti, D.	3	5	7	Wageningen University and Research Centre
Elazari, A.	3	6	6	Delft University of Technology
Hekkert, M.P.	3	7	6	Universidade de Sao Paulo - USP
Johnson, F.X.	3	8	6	Imperial College London
Jungmeier, G.	3	9	6	Chinese Academy of Sciences
Kaup, F.	3	10	5	Universidade Federal do Rio de Janeiro

Source: authors after Scopus (2019a)

Table 1 has a double ranking for authors and institutions which contributed in the studied field with scientific research. For instance, Levidow, L. has 5 personal contributions and is affiliated to The Open University from United Kingdom. He is closely followed by Kafarov, V.from Industrial University of Santander, Colombiaand Caniëls, M.C.J. and other authors with three contributions.

As overall contributions in top 10, from authors affiliated to a specific institution, four universities are from The Netherlands (Utrecht University, Technische Universiteit Eindhoven, Wageningen University and Research Centre, Delft University of Technology).

TABLE 2 - PAPERS DISTRIBUTION ON JOURNALS AND CONFERENCE VOLUMES

No	Journal or conference volume	Documents
1	Energy Policy	29
2	Rio Pipeline Conference And Exposition Technical Papers	20
3	Journal Of Cleaner Production	14
4	Renewable And Sustainable Energy Reviews	14
5	Bioresource Technology	13
6	Biomass And Bioenergy	11
7	Applied Energy	9
8	European Biomass Conference And Exhibition Proceedings	7
9	Technical Proceedings Of The 2009 Nsti Nanotechnology Conference And Expo Nsti Nanotech 2009	7
10	Biofuels Bioproducts And Biorefining	6
11	Energy Research and Social Science	6
12	Renewable Energy	6
13	Acta Horticulturae	5
14	Carbon Science And Technology	5
15	Chemical Engineer	5

Source: authors after Scopus (2019a)

Moving on to information included in Table 2, one can see that papers are distributed on journals and conference volumes directly related to the field of energy. Figure 3 shows there are three main areas which own more than 50% of the papers: Energy, Environmental science and Engineering.

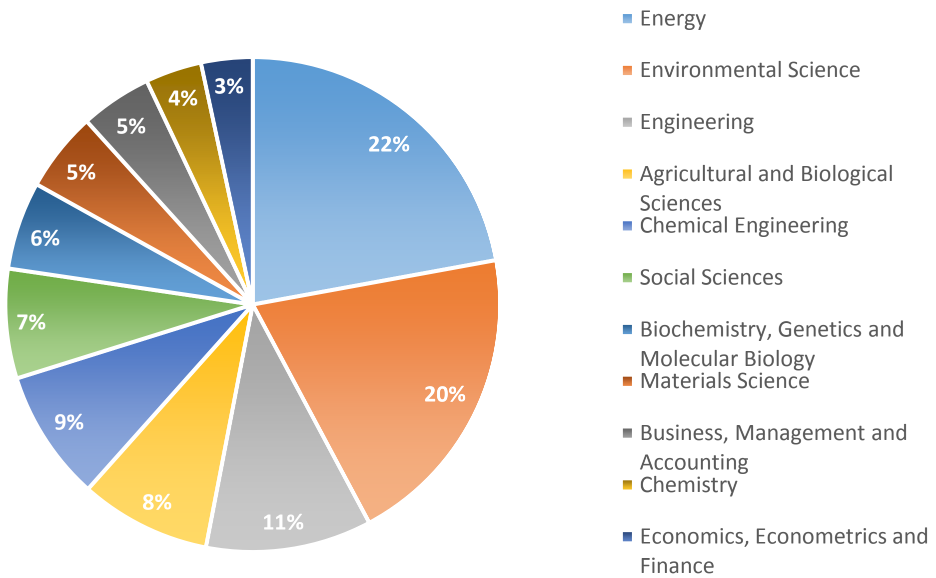

FIGURE 3 - SUBJECT AREA DISTRIBUTION OF THE PAPERS
Source: authors after Scopus (2019a)

4.2. Citations analysis

The growing interest for biofuel-innovation subject is shown not only by the great number of articles written and published in the last fifteen years, but also by the citations given to this articles. In the same time, the fact that the number of citations has an upward trend, means that the impact of the cited papers is growing, contributing to research development.

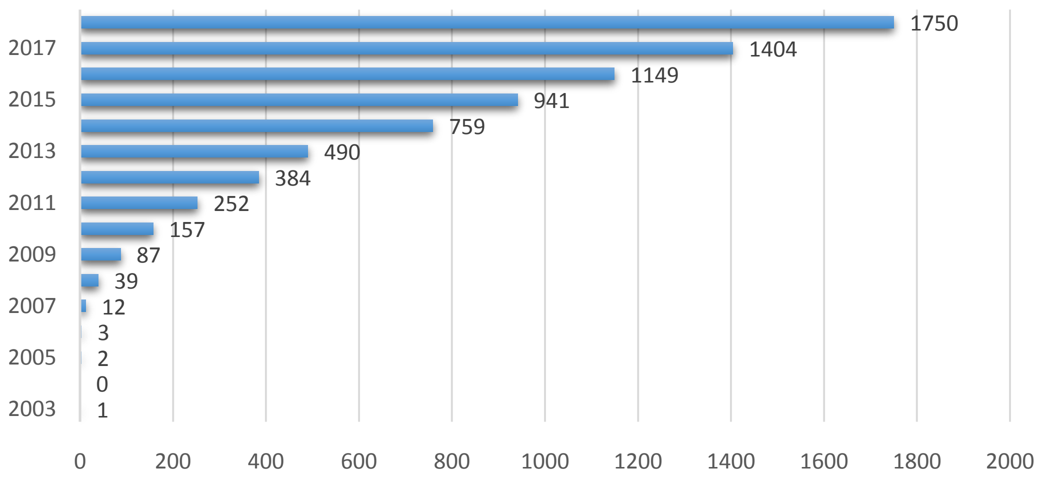

FIGURE 4 - CITATIONS RECEIVED BY YEAR
Source: authors after Scopus (2019b)

Starting with 2016, all 478 papers received more than a thousand citations each year, with real chances to exceed two thousands in 2019. The highest number of citations achieved in 2018 is due to papers such as: Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food

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security(Shiferaw et al., 2011)which received 67 citations in the last year, but also to papers recently published such as: Microalgae biorefinery: high value products perspectives (Chew et al., 2017), which received almost the same number of citations (65 citations).

As for the top 10 most cited articles presented within table 3, a ten year old publication of Semiat (2008) gathered the highest number of citations. At almost 100 citations away from the first place, an older publication of authors de Vries, van Vuuren & Hoogwijk (2007)finds its place in the ranking. Newer published papers struggle to rich and exceed 200 citations: Shiferaw et al. (2011) and Olguin (2012).

TABLE 3 - TOP 10 MOST CITED SCIENTIFIC PAPERS

No. crt.	Title	Authors	Citations
1	Energy issues in desalination processes	Semiat (2008)	342
2	Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach	de Vries, van Vuuren &Hoogwijk (2007)	250
3	Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security	Shiferaw et al. (2011)	200
4	Dual purpose microalgae-bacteria-based systems that treat wastewater and produce biodiesel and chemical products within a Biorefinery	Olguin (2012)	194
5	The new competition for land: Food, energy, and climate change	Harvey & Pilgrim (2011)	188
6	Recent advances in material science for developing enzyme electrodes	Sarma et al. (2009)	181
7	Combinatorial life cycle assessment to inform process design of industrial production of algal biodiesel	Brentner, Eckelman, & Zimmerman (2011)	180
8	Valorization of industrial waste and by-product streams via fermentation for the production of chemicals and biopolymers	Koutinas et al. (2014)	175
9	Disruption of microalgal cells for the extraction of lipids for biofuels: Processes and specific energy requirements	Lee, Lewis & Ashman (2012)	169
10	The Bioeconomy in Europe: An Overview	McCormick &Kautto (2013)	166

Source: authors after Scopus (2019b)

The newest paper in the top 10, of Koutinas et al. (2014), remarkably managed to gather 175 citations in only four years from publication. So, there are recent papers that receive citations faster than others indexed by the platform years before. Besides the quality and the relevance of the subject treated within their content, there is another thing that makes many papers receive so many citations: the benefit of being published by a reputable journal.

4.3. Keywords' analysis

In order to begin the keywords' analysis of the 478 selected papers, the authors had to download from Scopus information related to title, year of publication, authors, abstract and keywords. This information was useful for creating a map based on bibliographic data within the VOSviewer software. This software developed by Nees Jan van Eck și Ludo Waltman (2011) is able to support five types of analyses, among which the co-occurrence analysis of the keywords given by each author in each paper.

As counted by the software, there are 1200 keywords. A minimum number of 7 occurrences per keyword was chosen, in order to select only those keywords mentioned by at least 7 papers. It is relevant to explain the fact that by searching the two words, biofuels and innovation, in the abstract, title, keywords as fields,only 76 of them (a total of 478) "biofuels" was found as a keyword, and the singular form "biofuel" in only 32 of them. Probably in the rest of them, "biofuels" was part of the title or located within the abstract.

TABLE 4 - THE KEYWORDS' OCCURRENCES, CO-OCCURRENCES AND LINKS

No. crt.	Keyword	Occurrences	Links	Co-occurrences
1	Biofuels	76	19	69
2	Innovation	35	15	45
3	Biofuel	32	13	26
4	Biodiesel	25	13	26
5	Sustainability	23	13	32
6	Bioenergy	20	14	24
7	Microalgae	16	6	14
8	Renewable energy	15	11	18
9	Biorefinery	14	13	18
10	Bioethanol	13	9	15
11	Biomass	12	10	14
12	Bioeconomy	11	5	13
13	Climate change	10	9	15
14	Ethanol	9	8	13
15	Sustainable development	9	7	11
16	Biogas	9	7	8
17	Algae	8	7	13
18	Energy	8	4	6
19	Brazil	7	8	11
20	Policy	7	7	9
21	Life cycle assessment	7	6	6

Source: authors with VOSviewer

Table 4 presents all those 21 keywords, ranked after their occurrences. Links and co-occurrences are also provided. The 21 keywords were assigned by the program in four clusters marked with different colors in Figure 5.The red cluster is the largest one composed of seven keywords, while the smallest cluster includes only three keywords: the yellow one.The technique which helps assigning keywords to clusters is called VOS clustering and it was developed by Waltman, Van Eck, and Noyons (2010).

As explained in a previous paper (Cicea et al., 2019), the VOS clustering technique uses the number of nodes, the links between them, the total number of links and the total strength between them (the co-occurrence) and calculates for each node the distance from other nodes in order to find its location in a two-dimensional space (a representation called mapping). The positive integer number obtained after positioning a node represents the cluster that the node belongs to.

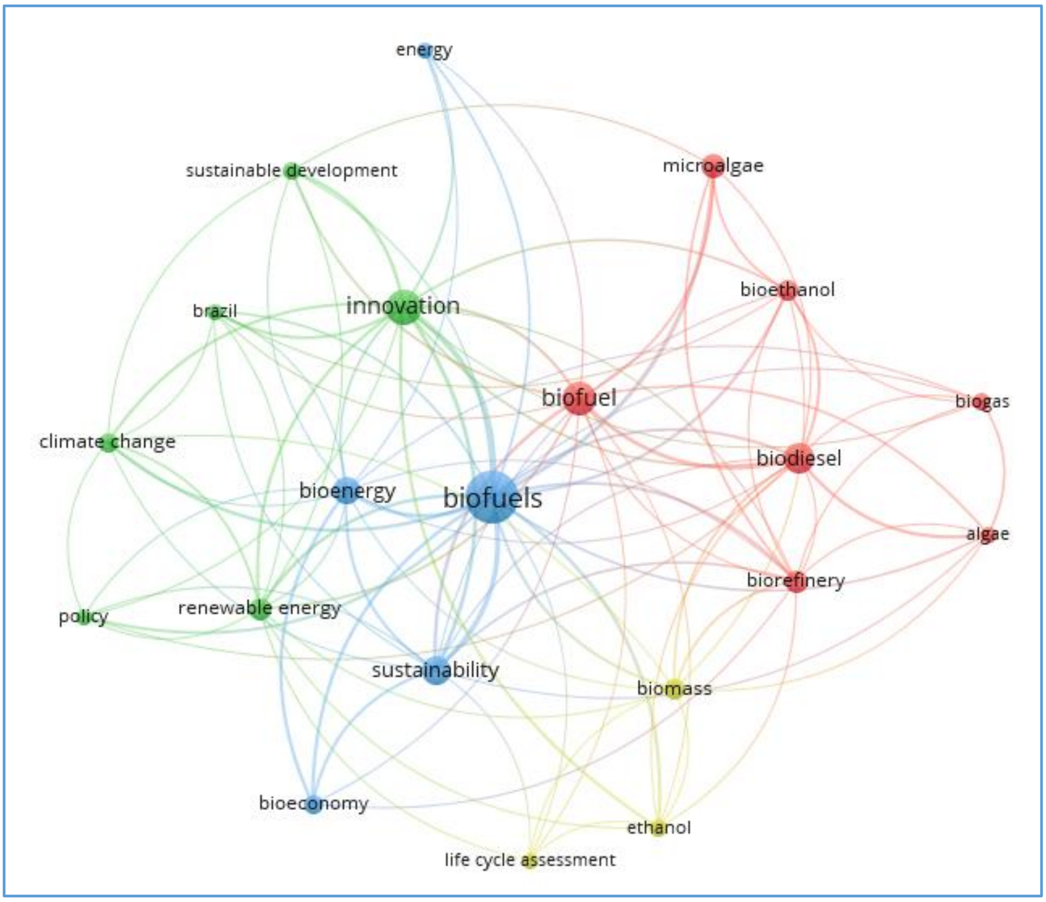

FIGURE 5 - THE KEYWORDS MAP (GROUPED IN CLUSTERS)
Source: authors with VOSviewer

The first map designed in Figure 5, has 21 nodes (according to the number of keywords with at least 7 occurrences, presented in Table 4). One can observe that the branches between those nodes differ in terms of thickness. Thicker branches describe a more powerful link strength, while a thinner branch report a weak co-occurrence link between nodes. The strongest co-occurrence link between keywords is the one formed between biofuels and innovation.

Another aspect to be discussed is the relatedness of keywords, which refers to the distance between them. So the proximity between bioenergy and biofuels shows a strong relatedness, while the fact that innovation is more distant from ethanol and biogas, shows a weaker relatedness.

The second map from Figure 6, refers to the period 2012-2017, for which the selected keywords are characteristic, and for which a high number of occurrences are reported. The map presents the focus on ethanol, sustainable development, energy and policy, as keywords related to research conducted in 2012 and till that year while 2017's research focuses on biogas.

The main evaluation tool used within this area appears to be the life cycle assessment.

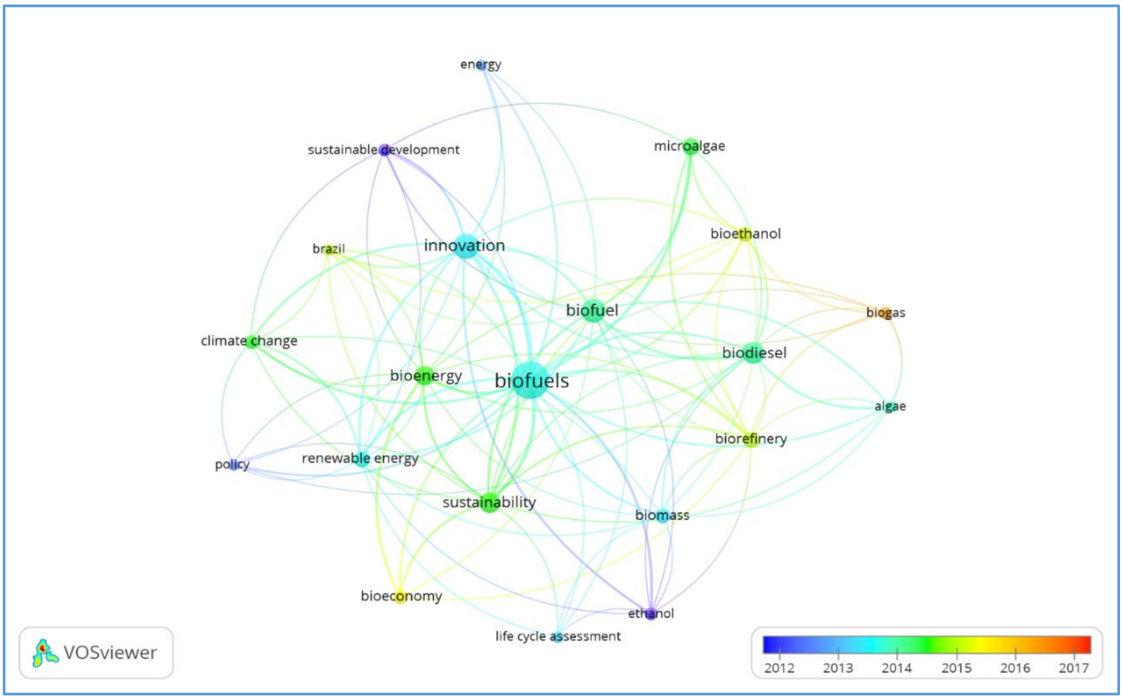

FIGURE 6 -MAPPING LINKS BETWEEN KEYWORDS IN TIME
Source: authors with VOSviewer

If changing the period to 2009-2012, the software reveals a map where the keyword sustainable development becomes representative for 2009 and preponderant to research developed starting with 2009 (the year of legislative initiatives on climate change and renewable, given the adoption of Directive 2009/28/EC of the European Parliament and of the Council) till 2012. Beginning with 2012, the interest of researchers moves from sustainable development to biomass, biofuels and innovation, and then to climate change, bioenergy and sustainability till 2015. Keywords characteristic to research developed through 2015 and 2016 are bioeconomy and bioethanol.

Another interesting thing that this map is stressing out is the fact that ethanol appears as a main keyword of 2012-2013, while bioethanol is prevalent to 2015-2016 period. Thus, the research slowly moves from concentrating on ethanol (which is a petroleum product or derived from petrochemicals, which come from fossil raw materials) to bioethanol (also called “renewable ethanol” which is ethanol obtained from biological contemporary matter) (Tamers, 2006).

4.4. Patents analysis

The patents evolution as presented by figure 7 shows an indefinite journey for innovation capacity within biofuels field between 2001 and 2008. An increasing trend characteristic to 2008-2013 period meets a similar trend (as shown by figure 1) of the number of papers published within that period. 2018 is characterized by a sharp drop in the number of patents which may be the result of a moving interest of the research area.

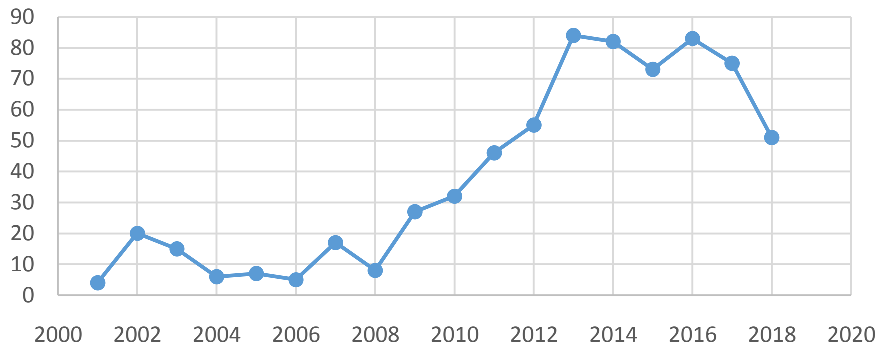

FIGURE 7 -PATENTS EVOLUTION AS RECORDED BY SCOPUS
Source: authors after Scopus (2019c)

According to Scopus database (2019c) there are four offices registering patents in the field between 2001 and 2018: United States Patent and Trademark Office Pre-Granted Publication (with 607 patents), European Patent Office (with 47 registered patents), World Intellectual Property Organization (with 25 registered patents) and United Kingdom Patent Application (with 11 registered patents). Table 6 provides a short list of the most relevant registered patents.

TABLE 5 - LIST OF PATENTS SORTED BY RELEVANCE

No	Patent name	Year	Patent Office
1	The Distributed Biofuel Manufacturing System (DBMS)	2010	US Patent and Trademark Office Pre-Granted Publication
2	Method for Biofuel Life Cycle Assessment	2009	US Patent and Trademark Office Pre-Granted Publication
3	Conversion of Carboxylic Acids to Alpha-Olefins	2015	US Patent and Trademark Office Pre-Granted Publication
4	Procedure for the production of biofuel from organic wastes	2011	US Patent and Trademark Office Pre-Granted Publication
5	Enhanced fuels, methods of producing enhanced fuels, and additives for enhanced fuels	2016	United Kingdom Patent Application
6	Self-sustainable mobile biodiesel production plant and method	2011	US Patent and Trademark Office Pre-Granted Publication
7	Lignin-Solvent Fuel and Method and Apparatus for Making Same	2012	US Patent and Trademark Office Pre-Granted Publication
8	Combustion system and method	2016	UK Patent Application
9	Method of Converting Triglycerides to Biofuels	2008	US Patent and Trademark Office Pre-Granted Publication
10	Diesel microemulsion biofuels	2013	US Patent and Trademark Office Pre-Granted Publication
11	A new microalgae chlorella for production of vegetal oil for biodiesel and cogeneration power units	2016	European Patent Office
12	Systems and methods for cultivating and harvesting blue water bioalgae and aquaculture	2014	US Patent and Trademark Office Pre-Granted Publication
13	Fuels for cold start conditions	2010	US Patent and Trademark Office Pre-Granted Publication
14	Method of cultivating algae	2016	European Patent Office
15	Systems and Methods for Biological Conversion of Carbon Dioxide Pollutants into Useful Products	2018	US Patent and Trademark Office Pre-Granted Publication

Source: authors after Scopus (2019c)

5. CONCLUSIONS

In the great world of biofuels, under the pressure of global challenges, research has followed a path meant to facilitate the development in the field and to support innovation. The findings of this paper reveal the main interest points of research related to biofuels, the main research topics as seen in time and the strong connection between biofuels and innovation, appearing more pregnant within the published papers between 2013 and 2014. As being situated in the same cluster, biofuels, bioeconomy and sustainability go all together, having a high degree of relatedness. From all keywords, one refers to a country, Brazil (the first so-called front-runner in the production of biofuels) and one refers to a tool used to evaluate environmental impact: life cycle assessment. On the considered period of time, no link reported between innovation and algae or microalgae. Also the research shows a slowly movement from concentrating on ethanol (prevalent in the 2012-2013 period of published papers) to bioethanol (dominant in the 2015-2016 period of published papers).

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