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A Model Study of Growth of Publications on the Field of Biofuels

Donaji Jiménez-Islas[1], Miriam E. Pérez-Romero[2,3], José Álvarez García[4*], María de la Cruz Del Río-Rama[5]

[1] Renewable Energy Division, Higher Technological Institute of Huichapan, TecNM, Hidalgo 42411, Mexico
[2] International Doctoral School of the UEx, PhD Programme R015, Universidad de Extremadura, Badajoz 06006, Spain
[3] Business Management Division, Higher Technological Institute of Huichapan, TecNM, Hidalgo 42411, Mexico
[4] Department of Financial Economic and Accounting, University Research Institute for Sustainable Territorial Development (INTERRA), Faculty of Business, Finance and Tourism, Universidad de Extremadura, Cáceres 10071, Spain
[5] Business Management and Marketing Department, Faculty of Business Sciences and Tourism, University of Vigo, Ourense 32004, Spain

Corresponding Author Email: pepealvarez@unex.es

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ABSTRACT

There is a great interest in biofuels production as an alternative and potentially renewable fuel. This study analyzed the rate of scientific publications related to the biofuels such as biodiesel, bioethanol, biogas, biohydrogen and wood pellets using the Logistic and Gompertz models to quantitatively describe the publications growth. The models showed fit to the biofuels growth data as indicated by the determination coefficient. China was the most productive country with publications of biohydrogen, bioethanol, biodiesel and biogas. Overall, research on the topic of biofuels, biohydrogen and bioethanol are increasing with a rate of publications greater than 0.26 years^{-1}. From 2003 there was growth in the rate of publications of each biofuel evaluated in this work.

1. INTRODUCTION

Biofuels are a type of fuels produced from living plant matter or byproducts of agricultural production [1]. The main advantages of using biofuels are related to lower pollutant emissions during their life cycle compared to fossil fuels, environmentally friendly and renewable [2, 3]. There are a variety of biofuels available in forms gaseous [4], solids [5] and liquids [6]. The development of society requires the incorporation of renewable and non-renewable energy for its comfort, which has given rise to a series of research projects that favor the development of science and technology.

In the field of science and technology, growth can refer to an increase in number of publications, institutions or scientists [7]. The publishing of original theories and experiments, typically in peer-reviewed journal, it is what propels scientific advancement; currently, the number of articles published in various journals, social and public media is expanding dramatically, with growth rates increasing considerably every decade [8].

Scientific activity related to the development of biofuels traditionally includes feedstock, pretreatment, chemical or biological processing and refining, the volume of publications is limited by the lack of publications comparing the global development by type of biofuels. In this sense, some publications have been conducted to describe each source of biofuel, however it is necessary to determine the rate of publication for each one and they can be analyzed using bibliometric methods and data modeling.

There has been a significant interest in the research community to evaluate the research activities using bibliometric analysis, during 2013, it was published a bibliometric evaluation of research output to map research activities and tendencies global biofuel field during 2003-2012, the temporal analysis confirmed that scientific outputs of biofuels field experienced a substantial growth with increasing publications and collaborations [9]. During 2018, a study was reported through the method bibliometric the characteristics of biomass energy and environment, this report revealed that has been becoming increasingly more extensive and global over the past 20 years, the period analyzed was from 1998 to 2007 [10], also in the same field, it was employed bibliometric methods to quantitatively and qualitatively evaluate the trend of the biomass energy related research literature from 1998 to 2013, the pace of publishing in this field increased rapidly over the last 16 years [11]. In other sense, a patent analysis bibliometric has been performed to explore the status and activities of technological development in the field of biofuels and biohydrogen, when the principal or predominant technologies for biohydrogen energy need a great deal of work to accelerate the development of hydrogen technology [12].

Several mathematical models have been developed for the purpose of quantitatively describing real data, in this context growth models play an important role to measure the prediction of growth of any subject in near future and help the policy makers to take necessary actions to improve the results [13]. Bornmann and Mutz [14] applied some models to describe the growth, the authors reviewed the number of publications and cite references using a simple exponential growth $y_{(t)} = y(0) * Exp(b_1 - t)$ where b_1 is the growth constant, t is the time (year), this model was completed with a statistical analysis of (R^2)=0.96 (p<0.05). Also, in the field of the neurology was reported the research in India and China, they are concluding that the growth of literature in neurology does not follow either the linear growth model or logistic growth model, but it nearly follows the exponential growth model [15]. In other sense, it was discussed several growths of groundnuts research under exponential model, linear and logistic models, where the logistic growth is not fit because its value is high from presumed values, so exponential and linear growth models are better found in the study [13]. Another example of the application of the growth models was in the hydrogen energy field that may be fitted by an exponential model [16]. Also, it was reported that the rate of scientific publications on the subject of biofuels in Latin America countries using the logistic model to fit data [17]. With these tools available the evolution of scientific literature can be analyzed and interpreted by government agencies to take the political public for facilities to mitigate the change climate, however, it is necessary the analysis of the rate in each source of biofuels. In this study, a comprehensive bibliometric analysis was used to trace global trends to each type of biofuels using information from 1980 to 2019 of database Web of Science, the data were fitted and employed the logistic and Gompertz models to describe the rate of publications in the field.

2. MATERIALS AND METHODS

In this study, the following phrases were used to search titles, abstract and keywords in the database of the Web of Science (WoS): TITLE-ABS-KEY ("biodiesel" OR "bio diesel"); TITLE-ABS-KEY ("bioethanol" OR "bio ethanol"); TITLE-ABS-KEY ("biohydrogen" OR "bio hydrogen"); TITLE-ABS-KEY ("biogas" OR "bio gas"); TITLE-ABS-KEY ("wood pellet*"); (TITLE-ABS-KEY (biofuel*). In this case the period was from 1980 to 2019.

The sign (*) in the search box was used to obtain both singular and plural versions of a keyword, and the marks (" ") were used for exact phrases search. The data were analyzed using Microsoft Excel 2013. Bibliometric indicators were extracted and analyzed both quantitatively and qualitatively.

The time trend of the publications was analyzed by fitting mathematical models with Microsoft Excel 2013 and solver function, the logistic (Eq. (1)) and Gompertz (Eq. (2)) growth models were used to adjust the profile of documents in the field [17].

$$P(y) = \frac{P_{max}}{1 + \left(\frac{P_{max}}{P_0} - 1\right) e^{-\mu y}} \quad (1)$$

$$P(y) = a e^{-b e^{-\mu t}} \quad (2)$$

where, the symbol *P(y)* represents the cumulative volume of documents by year, *Pmax* maximum number of documents, *Po* initial number of documents, y year, μ specific growth rate of publications, asymptotic publications, b an integration constant related to initial publications and t is time.

The data were used to fit all parameters using the solver function on Microsoft Excel 2013, The simulation program was designed to achieve the minimal normalized error using solver function and the data of WoS were fitted to determine the value of specific growth rate (μ). The results of WoS and the generated model were analyzed using regression curve fitting with statistical significance set at $p=0.05$ with data analysis of Microsoft Excel 2013. It was estimated the determination coefficient (R^2). The data download from WoS was imported into Microsoft Excel 2013 and VOSViewer software which was used to create network maps. The instructions are the next: Create a map based on bibliographic data, read data from bibliometric database Web of Science, files, type analysis Co-authorship-countries (unit of analysis), full counting, maximum number of countries per document (25), minimum number of documents of a country (10). The VOSviewer software was used to create the bibliometric network maps for co-authorship and countries.

3. RESULTS AND DISCUSSIONS

The distribution of document types and language were identified on WoS database. The Table 1 compares the results obtained from the bibliometric analysis, in all cases, the article is the more important document type for the biofuels, biodiesel, bioethanol, biohydrogen, pellets and biogas; the review is the second document type prefer by authors in the field of bioenergy.

In the case of language, around 99.4% of the documents have been published in English for biohydrogen, 97.8% for biofuels, 97.3% for biodiesel, 96.85% for bioethanol, 96.2% for biogas and 95.85 for pellets. Other major publishing languages included Spanish, German, Czech, Polish and Portuguese.

According to the study of He et al. [18], many researchers will publish the research results in English in order to facilitate communication and improve the influence of their research. In the same way [19] describes in liquid biofuels the interest in internationalizing the information.

Table 1. Language and document type of publications in the bioenergy field

	Bio-fuels	Bio-diesel	Bio-ethanol	Bio-hydrogen	Pellets	Bio-gas
Document						
Article	81.974	89.268	87.17	87.665	93.69	90.56
Review	11.437	7.203	9.616	10.777	4.89	7.19
Languages						
English	97.8	97.3	96.85	99.473	95.85	96.20
Spanish	0.344	0.328	0.452	0.132	0.24	0.45
German	0.347	0.313	0.812	-	0.49	1.47
Czech	0.143	0.027	0.552	-	-	0.11
Polish	0.288	0.252	0.326	0.11	1.07	0.68
Portuguese	0.471	1.135	0.184	0.088	0.16	0.46

3.1 Trends based on publication year and modeling, biofuels

Figure 1 shows the network among 112 countries of international co-authorship. The size of each circle shows the number of publications written by authors from the country and each link between circles of different countries indicates there is a co-authorship between institutions of those countries.

The largest set of connected countries consist of 112 countries in 11 clusters. The clusters are formed by the frequency of co-occurring terms representing each country. As shown in Figure 1, the USA, China, India, Brazil, Germany are the countries with the greatest number of biofuels publications.

It is notable that the number of publications yearly from 1980 to 2002 was less than 100, after 2002 until 2006 there was a stage of acceleration where the number of publications increased nearly four times, more than 96.5% of the records were published during the period 2007-2019, in this stage there is a development exponential of publications of biofuels, Figure 2. In other study, Konur [20] evaluated the research on the bioenergy from biomass, the literature has growth exponential, similarity of this work.

Comparisons between the two models were made using the solver function, the results showed that the growth rate were μ=0.2753 $year^{-1}$, R^2 =0.9743 (Gompertz model) and μ=0.2614 $year^{-1}$, R^2=0.9985 (Logistic model). It was shown that the Gompertz model describes in the best way the evolution of publications in the field of biofuels. Growth of publications of biofuels is a phenomenon that has influenced the interests of researchers, encouraging them to find solutions to reduce CO_2 emissions [21]. In the same way, the development and implementation of government policies for the research determined the growth of publications, additional to that the development of programs to study different sources of renewable energy to substitute fossil fuels [22]. In addition, Bórawski et al. [23] describe that to comply with climate protection and resource efficiency, the development of a sustainable bioenergy market based on biological resources is needed, which generates growth in knowledge.

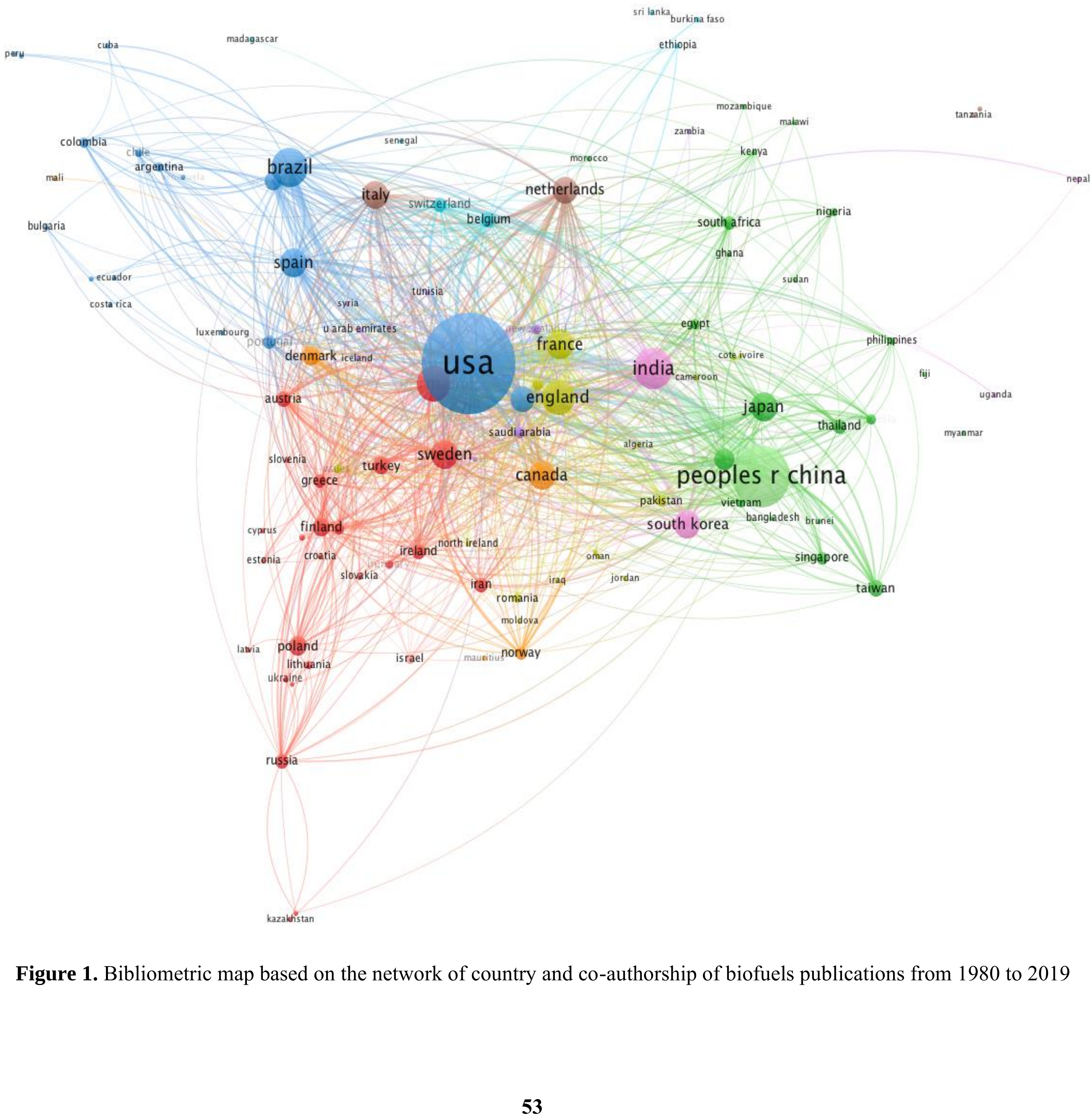

Figure 1. Bibliometric map based on the network of country and co-authorship of biofuels publications from 1980 to 2019

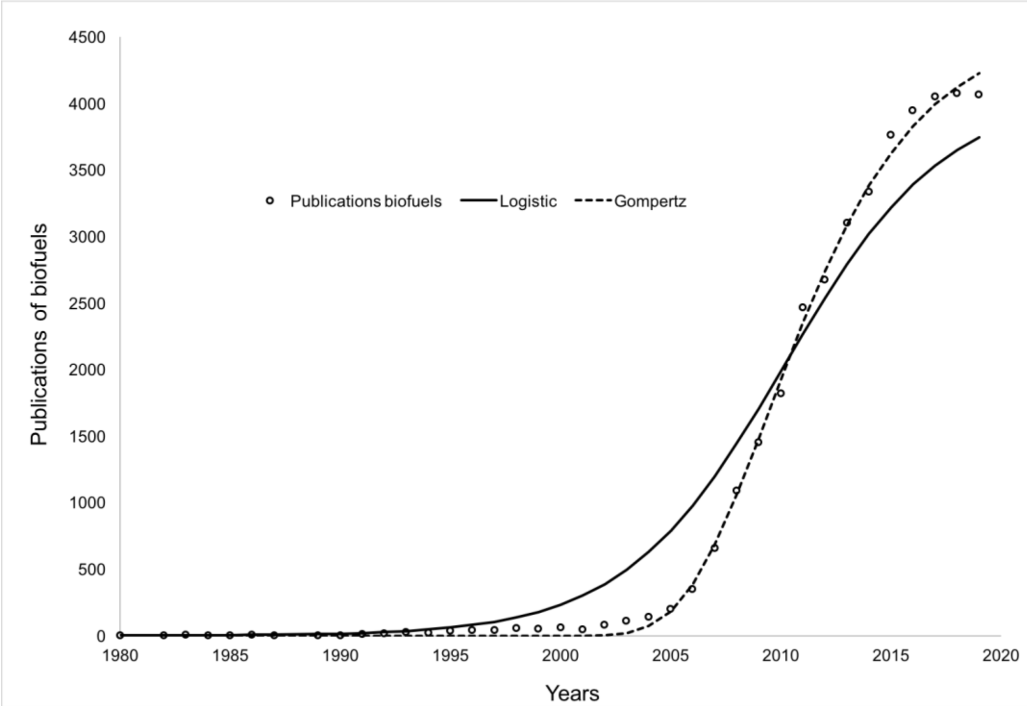

Figure 2. Number of publications of biofuels from 1980 to 2019, (º º º publications, WoS;—Logistic model; -----Gompertz model)

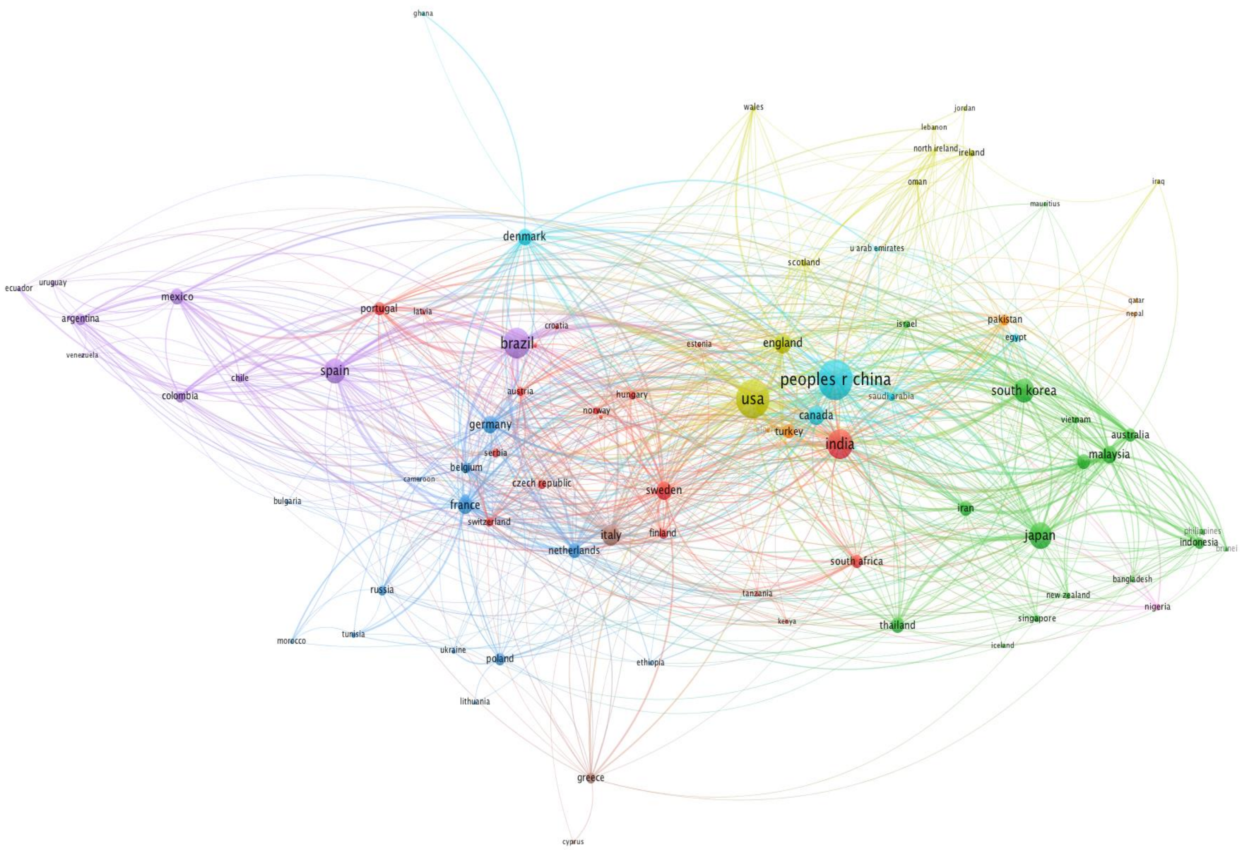

Figure 3. Co-authorships map for most active countries in the of publications of bioethanol from 1980 to 2019. Coauthorship-countries of publications of biodiesel from 1980 to 2019

3.2 Bioethanol

As shown in Figure 3, 85 countries and 9 clusters were formed to describe the interaction between nodes, the top 5 more influential countries are China, USA, India, Brazil and Japan. We can distinguish between clusters of the USA and China through a direct interaction of collaboration. The USA is the node more important in the field of bioethanol and develops an interaction with the rest of nodes. Among these clusters, main organizations are Chinese Academy of Science, University of São Paulo and Tianjin University.

From 1983 to 2005, few studies have been published in the bioethanol field (studies<100/year), between 2006 to 2012, there has been a growing number of publications (>100/year<1000/year), the principal findings of publications of bioethanol showed that between 2013 and 2019 the growth was higher compared to the previous stages, Figure 4.

The top 5 journals where researchers published documents of bioethanol headed by Bioresource Technol, after Biomass & Bioenergy, Applied Microbiology and Biotechnology, Biotechnology engineering and Renewable and Sustainable Energy Reviews. There are similarities between the growth rate of models applied to publications of bioethanol, the μ=0.2692 $year^{-1}$, R^2 =0.9997 (Gomperz model) and μ=0.2632 $year^{-1}$, R^2=0.9709 (Logistic model). With respect to keywords were searched "bioethanol", "fermentation", "Ethanol production", "Bioethanol production", "Ethanol", "Biomass", "Pretreatment", "Enzymatic hydrolysis", "Lignocellulosic biomass" and "Bio-ethanol.

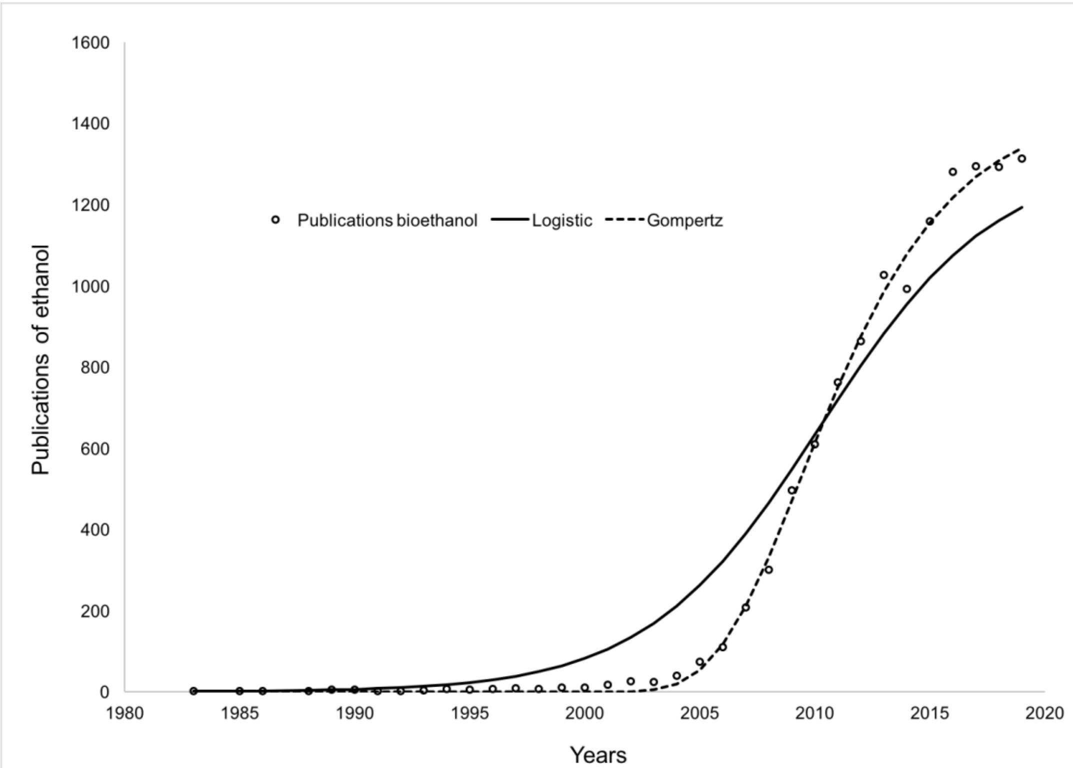

Figure 4. Number of publications of bioethanol from 1980 to 2019, (º º º º publications, WoS;—Logistic model; -----Gompertz model)

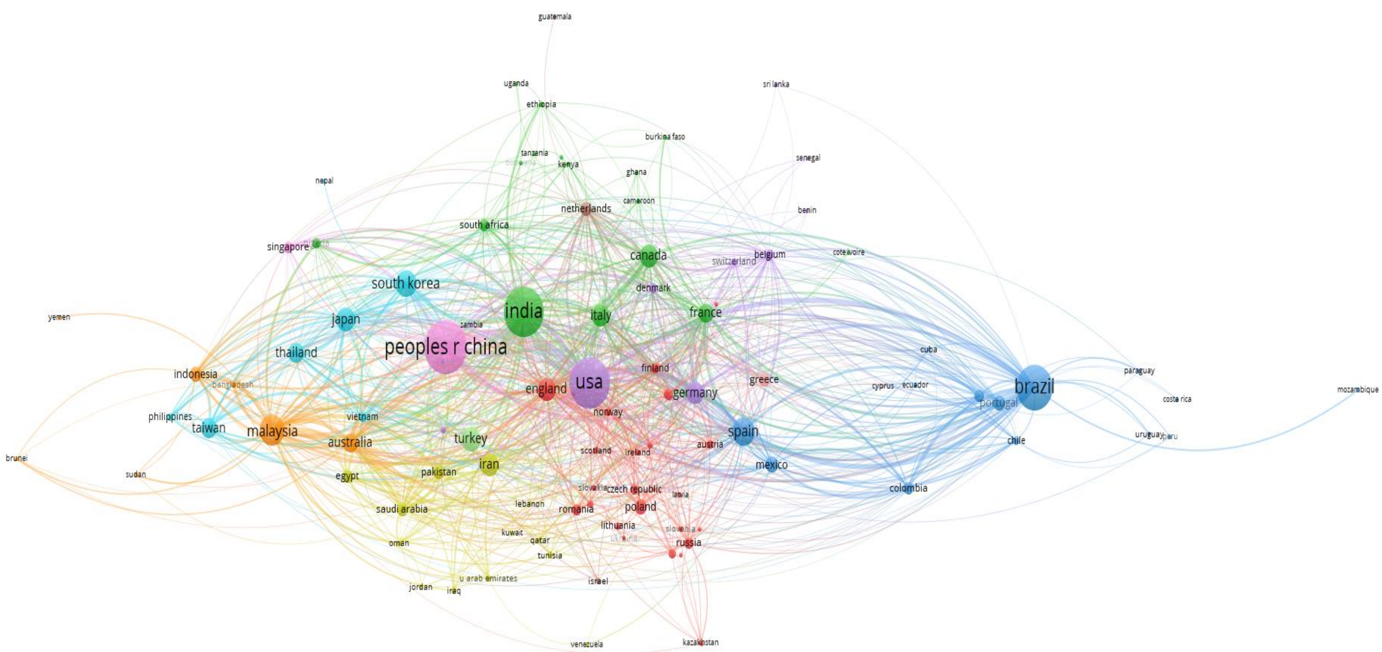

Figure 5. Co-authorship-countries of publications of biodiesel from 1980 to 2019

3.3 Biodiesel

Figure 5 reveals that there has been a marked influence in the field of biodiesel between the countries China, USA and India. In this case, Brazil is the country with regional influence. Similarly, Benavides-Gamero et al. [24] found that the most productive countries in biodiesel production (publications) were China (16.4%), India (12.3%), Brazil (10.1%) and USA (8.5%) using the HitsCite FN Thomson Reuters Web Knowledge metadata. In this study, 11 clusters were formed to describe the interaction between nodes, interestingly, the research on biodiesel was centralized in Asia, followed by America.

The results obtained from 1991 to 2002 suggest that few studies have been published in biodiesel (<1% of publications), however, the rate of growth of publications was 6.9% between 2003 and 2008. The Figure 6 shows that there is an important growth of publications in the field of biodiesel (92%) from 2009 to 2019. The number of articles of biodiesel under supercritical conditions increased from 3 in 2001 to 31 in 2019 [25]. Similarly, Zhang et al. [26] found that the number of publications of biodiesel rose significantly from 2014 in the Science Citation Index Expanded, under the study bibliometric of biodiesel research during 1991- 2015.

Comparisons between the two models showed that the growth rate were μ=0.2074 $year^{-1}$, R^2=0.9959 (Gompertz model) and μ=0.3879 $year^{-1}$, R^2=0.9975 (Logistic model). It was shown that the Gompertz model describes in the best way the evolution of publications, Figure 6.

The top 5 journals where researchers published documents of biodiesel headed by Fuel, after Bioresource Technol, Energy and Biofuels, renewable & Sustainable Energy, and Renewable Energy. The institution more influential was Chinese Academy Sci. With respect to keywords were searched "biodiesel", "transesterification", "biodiesel production", "microalgae" and "oil".

3.4 Biohydrogen

In order to create a map for co-authorship in countries, co authorship and countries were selected and the created map is shown in Figure 7. According to the results, it is seen that China, India, USA, Taiwan and South Korea are the leading countries in this field. China has the most significant collaboration with the USA, as can be seen from the higher line thickness. Each cluster represents a group of intensively related items whose relation is strong enough to form a separate entity; in order to exist as such, it is obliged to create "relations" with other, similarly formed, separate entities [27].

Biohydrogen is an alternative energy source, various biological routes are there for H_2 production including bio-photolysis, photo fermentation, dark fermentation process, or a combination of these processes [28]. To explore the historical and present growth of publications of biohydrogen a number of authors have mainly been interested in analysis of growth in the las years, Tsay [16] examined that the literature of hydrogen energy may be fitted relatively well by an exponential fit as Y= 482+12e0.176(x-1965), when the annual growth is around 18%. In Figure 8 there is a clear trend, the literature linked to biohydrogen research increased sharply after 2003 and research the maximum number in 2019, in the same vein, Chandrasekhar et al. [29] analyzed the data from the biological routes for the production of biohydrogen, in this study the literature increased year by year after 2003.

Since 2004, a rapid and steady growth trend in accumulative publications (Figure 8), which confirms that the biohydrogen has gained more popularity for researchers recently. By examining the number of publications of biohydrogen, there was a positive fit between the data and models, where the rate of growth was μ=0.2752 $year^{-1}$, R^2 =0.9769 (Gompertz model) and μ=0.2120 $year^{-1}$, R^2=0.9542 (Logistic model). In this same context, Jiménez-Islas et al. [22] reported a lower rate of 0.176 using an exponential fit. It was shown that the best model to fit the data of publications of biohydrogen was to Gompertz model.

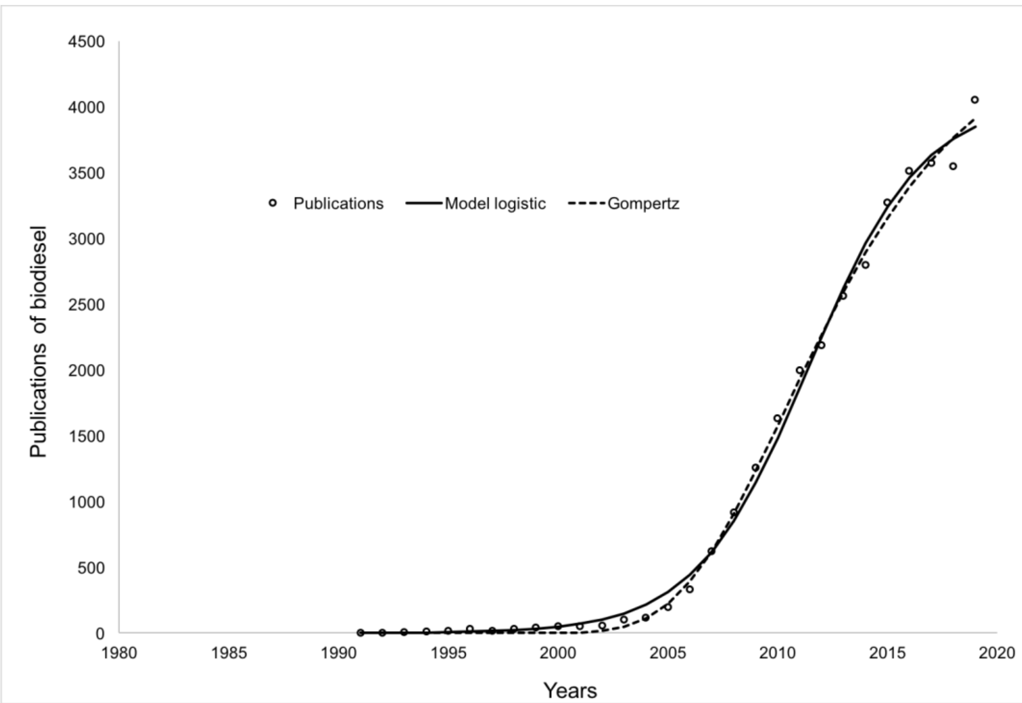

Figure 6. Number of publications of biodiesel from 1980 to 2019, (ᵒ ᵒ ᵒ ᵒ publications, WoS;—Logistic model; -----Gompertz model)

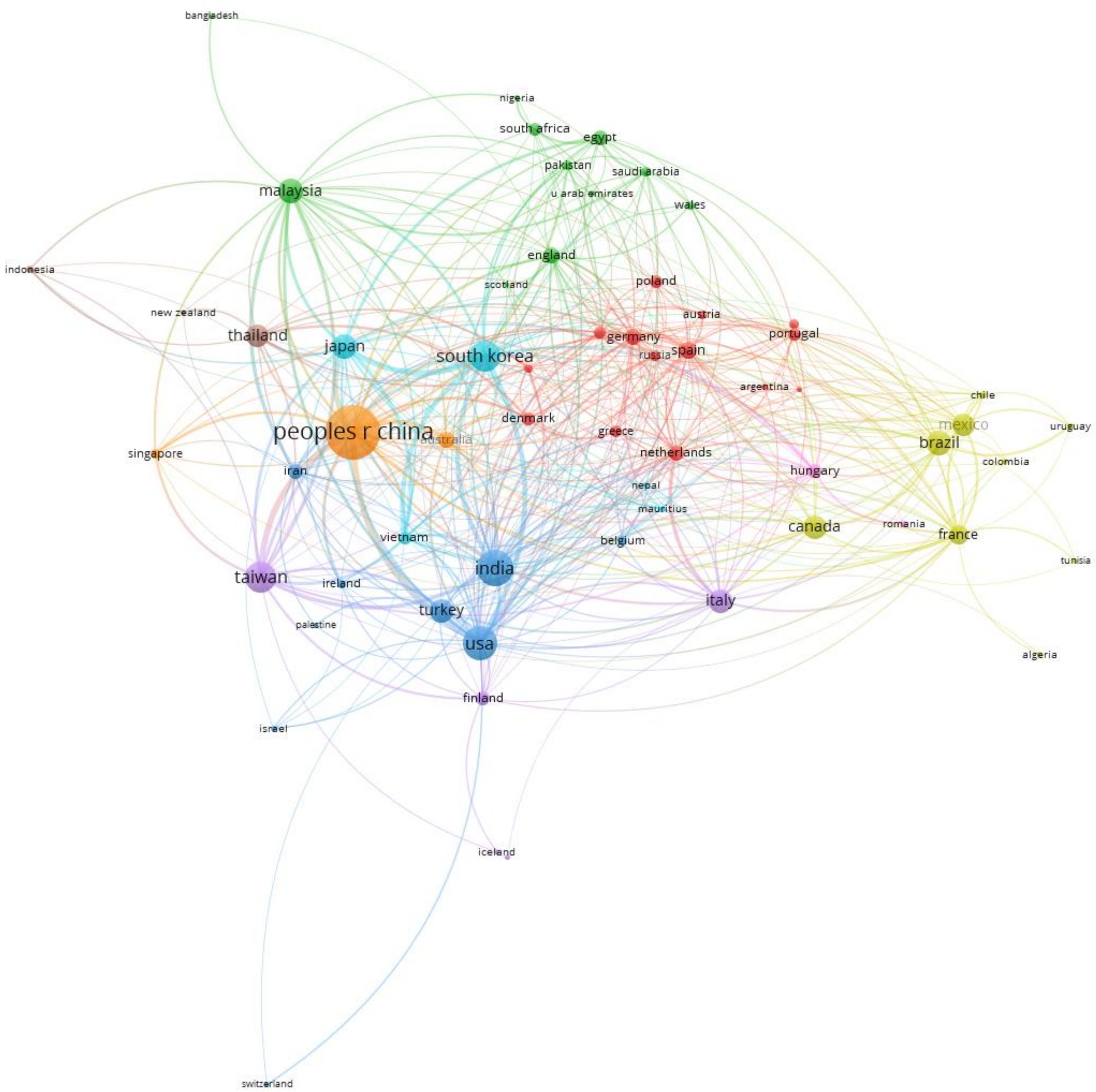

Figure 7. Co-authorship-countries of publications of biohydrogen from 1981 to 2019

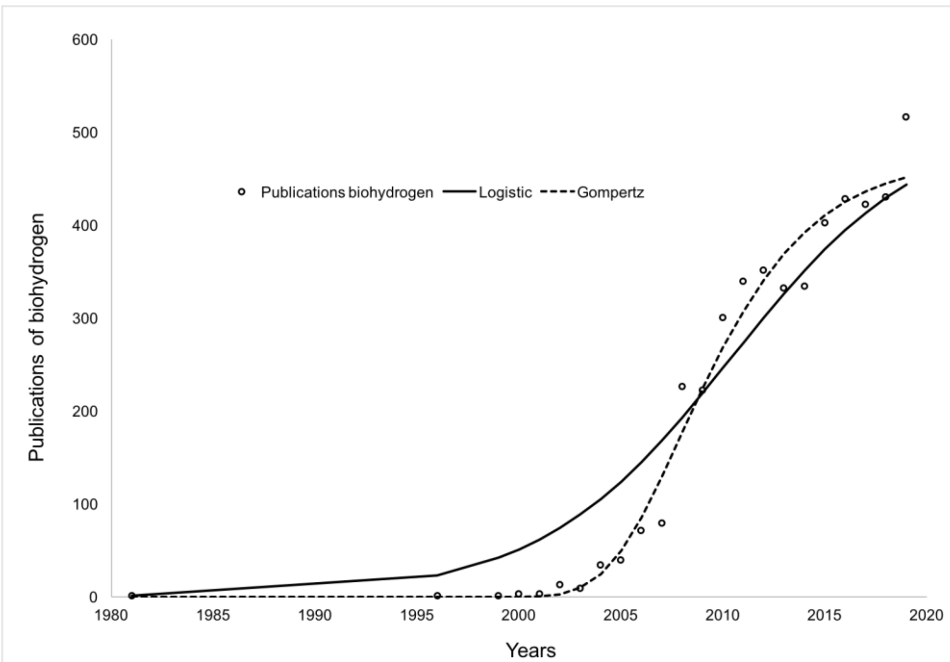

Figure 8. Number of publications of biohydrogen from 1981 to 2019, (ᵒ ᵒ ᵒ ᵒ publications, WoS;—Logistic model; -----Gompertz model)

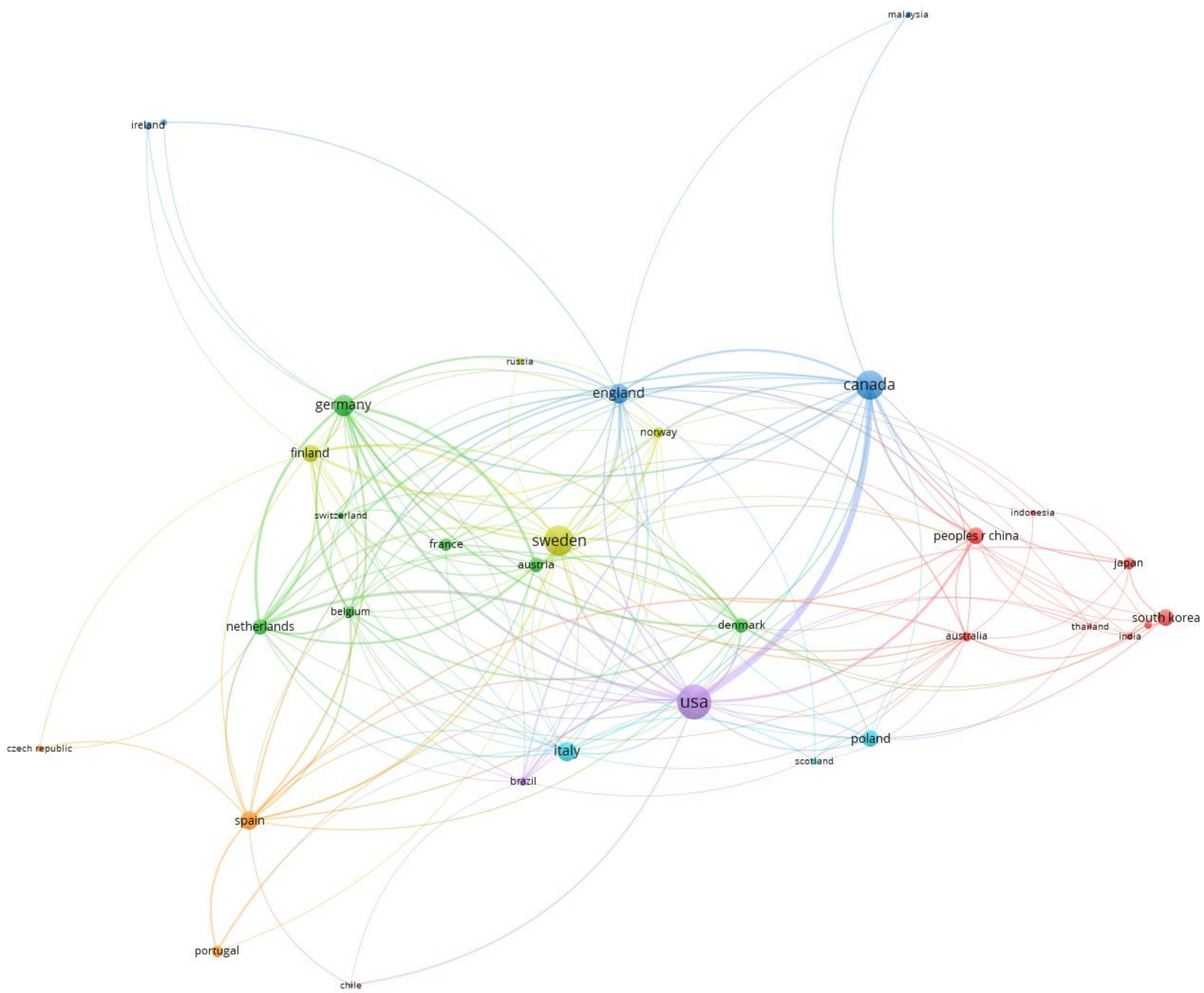

Figure 9. Coauthorship-countries of publications of wood pellet from 1983 to 2019

3.5 Wood pellets

The country affiliation provides information about the country in which the authors worked, within a certain research institution, at the time they were publishing their articles [30]. The co-authorship collaboration has been integrated in Figure 9, each node represents a country and the thickness of the line represents the frequency of co-authorship collaboration among the countries. The USA, Canada and Sweden are by far the most active of the co-authorship collaboration countries, seen from the size of the circles and the line with different thicknesses between the USA and other countries. The clustering analysis shows 8 major cooperation groups, indicating that these are similar to each other in the co-authorship collaboration network represented by University British Columbia, Oak Ridge National Laboratory, Swedish University of Agricultural Sciences, Utrecht University and Umeå University.

Wood pellets are the most common form of internationally traded solid biomass for energy use and this material do vary according to ash content, energy content, bulk density, and moisture content; The European Union is a major consumer in the wood pellet market [31]. The publication of documents of a research field help to identify potentially high relevant information about the development of the wood pellet. In this section was determined the evolution of publications between 1983 and 2008, the rate of publication on wood pellets grew by about 9.46%, from 2009 to 2019. The pace of publication increases substantially, with an average annual growth rate greater 90.53%, Figure 10.

In the same way, we have observed that the logistic model fits much better than logistic model in the data of wood pellets publications, in this context, the rate of growth was μ=0.1356 $year^{-1}$, R^2=0.9858 (Gompertz model) and μ=0.1949 $year^{-1}$, R^2=0.9373 (Logistic model). The rate of publications of wood pellets was less extensive in comparison with biofuels, biodiesel, bioethanol and biohydrogen, the rate not over 0.2 $year^{-1}$.

The analysis of journals is also an interesting topic, because it helps to find the most possible journals to publish relevant studies and this analysis could be useful to the researchers in planning for publication their research work [30]. The most influential journals in the field of wood pellets are Biomass and Bioenegy, Fuel, Energy & Biofuels, Applied Energy and Fuel Processing Technology. The keywords are generalizations of the topic in the literature. Authors tend to list a number of keywords that facilitate framing the scientific contribution in the field or subject matter most closely related to the topic addressed in their study [30]. The top 5 of the keywords most used by researchers were “Biomass”, “Wood Pellets”, “Combustion”, “Bioenergy” and “Pyrolysis”.

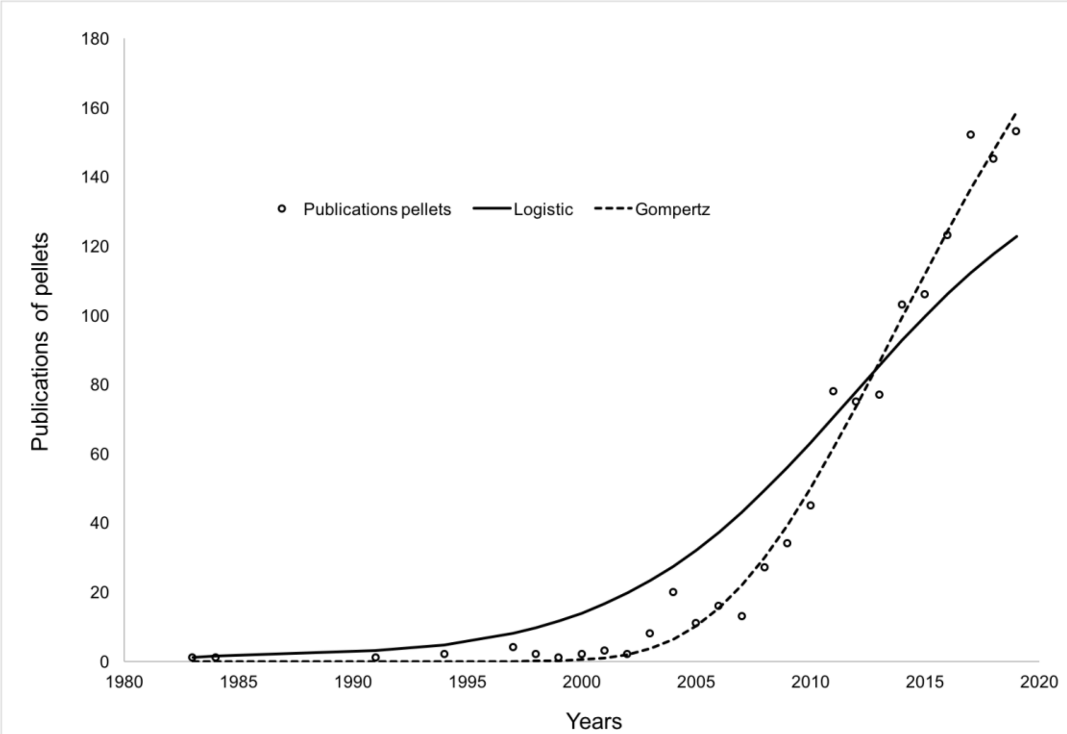

Figure 10. Number of publications of wood pellet from 1983 to 2019, (° ° ° ° publications, WoS;—Logistic model; -----Gompertz model)

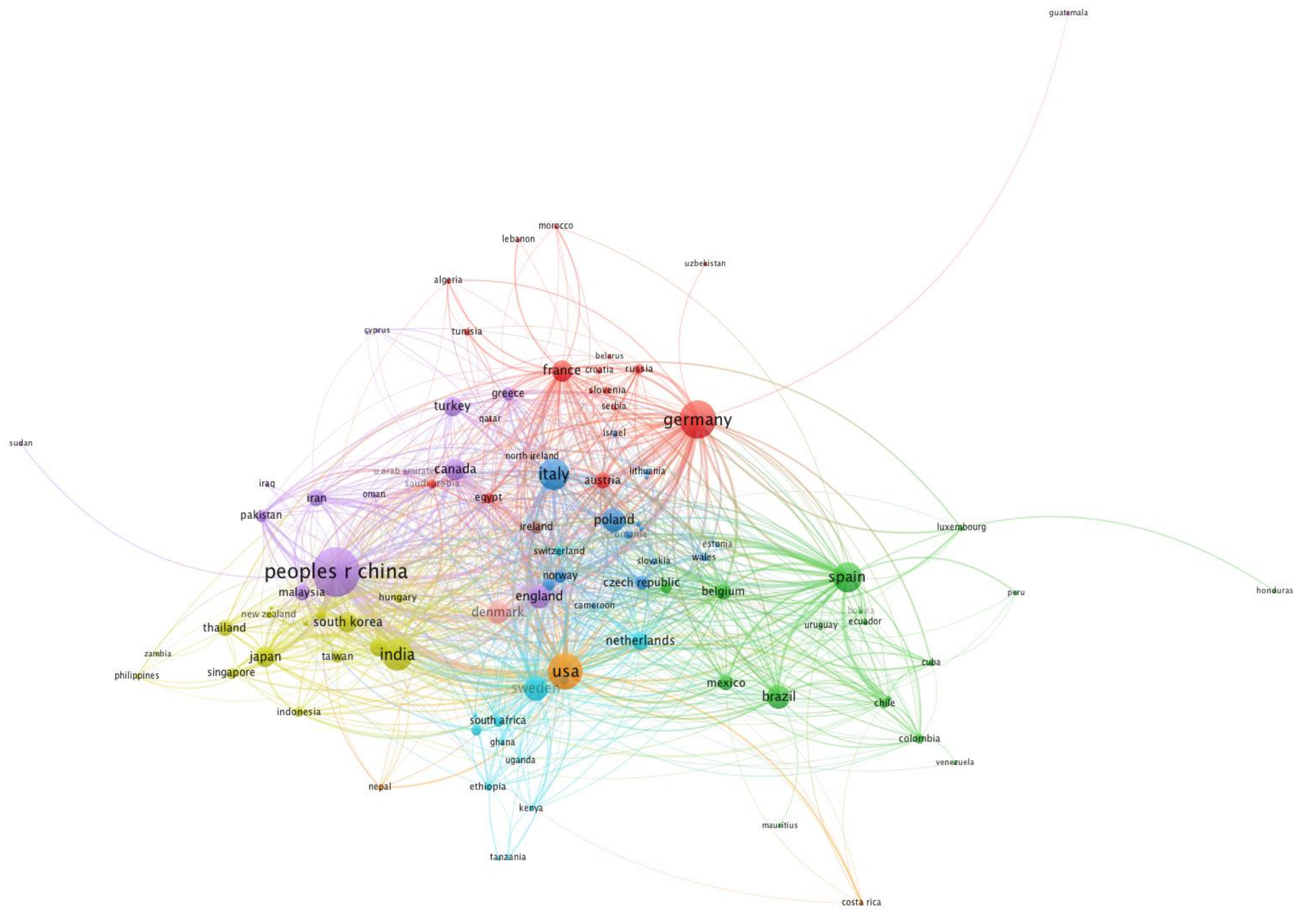

Figure 11. Co-authorship-countries of publications of biogas from 1980 to 2019

3.6 Biogas

Country co-authorship analysis can be reflecting the degree of communication between countries as well as the influential countries in the field of biogas. The country co-authorship network is shown in Figure 11, the big nodes represent the influential countries, as we can see, the more influential countries in the field of biogas are China, Germany, USA, India and Italy.

The Chinese Academy of Sciences is an institution with a high level of the scientific production of China. Moreover, Germany is the second country in the rank and is the largest biogas producer in the world [32, 33]. In same context, the importance and role of biogas in energy production is growing in countries Europe, this can be seen in the case of promote of renewable energies by guaranteed refund prices or emission trading systems [34]. In Latin America Brazil lead the biogas publications, this result is similar to those reported by Rincon et al. [35] who showed that Brazil being the leader with the greatest number of articles published as research results of biogas, followed by México, Colombia and Chile.

Biogas is alternative renewable energy composed mainly of methane (50-75%), CO_2 (25-45%), water (2.7%) and other gases in small volumes [36]. Biogas is assumed a green sustainable gas produced by the anaerobic digestion of organic agricultural waste, manure, municipal waste, digester materials, sewage, green waste or food waste [37]. For production, four stages are carried out in the process: anaerobic digestion, hydrolysis, acidogenesis, acetogenesis and methanogenesis [38]. In addition, the treatment of biogas is of great importance to ensure the reduction of pollutants such as H_2S and CO_2 [39]. There is a large volume of published studies describing the importance of biogas, the Figure 12 shows the evolutions of publications of biogas, the period between 1980 and 1990 was characterized by a low number of publications (1.86%), during a second period, between 1991 and 2005 with a mean < 1% publications per year, and the more productive period between 2006 and 2019 with 89.71% of the growth of publications of biogas. One possible reason for this occurrence might be attributed to the increased interest in the development of renewable energy [32].

In relative terms, the growth rates were μ=0.04 $year^{-1}$, R^2=0.9957 (Gompertz model) and μ=0.13 $year^{-1}$, R^2=0.867 (Logistic model). Between 2003 and 2019 the publications rate increased rapidly, this increasing trend in research production can be result of the emergence of a fossil energy crisis, the increase in the price of energy, and the general improvement of social awareness [40].

With the profile of grow of biogas, the Gompertz model describes in the best way the evolution of publications in comparison with the logistic model. In other work, Rincon et al. [35] showed that 58.6% of the publications of biogas are located in the period 2014-2017, which shows that the issue has become increasingly relevant among the scientific community and its rise is mainly due to increased environmental awareness and the goal of many countries to meet emissions targets and reduce the carbon footprint.

The total number of publications was found that Bioresource Technology, Water Research, Renewable and Sustainable Energy Reviews, International Journal of Hydrogen Energy and Biomass Bioenergy were the top 5 more productive journals. In the field studied in this article, it was found that the keywords more used was “biogas”, followed by “Anaerobic digestion”, “biogas production”, “Methane” and “Anaerobic-digestion”.

4. CONCLUSION

This study, we conducted a bibliometric analysis of publications of biofuels, bioethanol, biodiesel, biohydrogen, wood pellets and biogas using modeling of data. The findings from this work include the following:

-The amount of publications in the area of biofuels is increased. Of the publications obtained, there is an increase in the research from 2003 in each topic studied, it can be attributed to several factors such as the development of policies to mitigate CO_2 emissions.

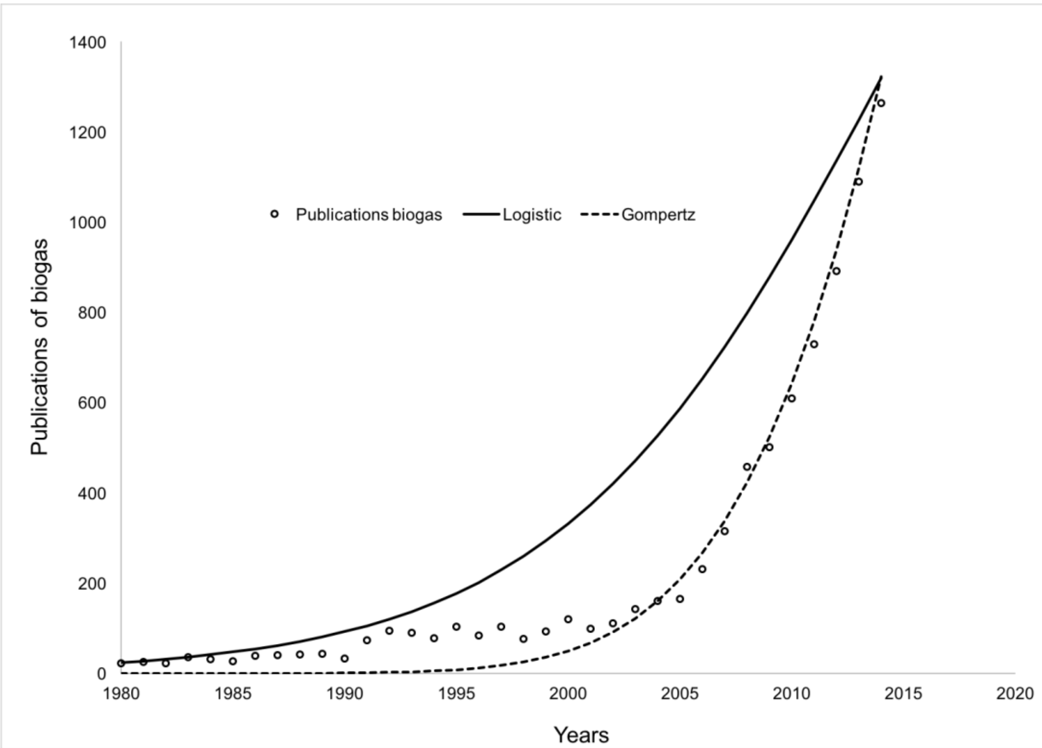

Figure 12. Number of publications of biogas from 1980 to 2019, (ᵒ ᵒ ᵒ ᵒ publications, WoS;—Logistic model; -----Gompertz model)

-The biofuels, biohydrogen and ethanol have the highest rate of growth according to the Gompertz model.

-In terms of countries, China had the greatest productivity of publications in the field of biohydrogen, bioethanol, biodiesel and biogas; The USA had productivity of publications to biofuels and pellets.

The present work has constructed comprehensive knowledge of different biofuels growth researches, which provides a form to describe the growth of using models to estimate the rate of publications. Overall, this bibliometric analysis is aimed at helping the academics working in the biofuels production research area and it is a tool of analysis to predict the development of publications in the field of biofuels.

The present research contributes to the field of bibliometrics by establishing a way to estimate the rate of scientific publications in different fields, regardless of the size of a country, researchers and universities, in order to measure and compare productivity under a publication rate factor. In this research, we applied it to the biofuels sector, but it can be applied to other fields of knowledge.

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NOMENCLATURE

(R^2)	Determination coefficient
WoS	Web of Science

Greek symbols

μ	Specific growth rate, h^{-1}

Subscripts

CO_2	Carbon dioxide