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Biomass as Renewable Energy: Worldwide Research Trends

Miguel-Angel Perea-Moreno [1], Esther Samerón-Manzano [2] and Alberto-Jesus Perea-Moreno [1,*]

[1] Departamento de Física Aplicada, Universidad de Córdoba, CEIA3, Campus de Rabanales, 14071 Córdoba, Spain; k82pemom@uco.es

[2] Faculty of Law, Universidad Internacional de La Rioja (UNIR), Av. de la Paz, 137, 26006 Logroño, Spain; esther.salmeron@unir.net

* Correspondence: g12pemoa@uco.es; Tel.: +34-957-212-633

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Abstract: The world's population continues to grow at a high rate, such that today's population is twice that of 1960, and is projected to increase further to 9 billion by 2050. This situation has brought about a situation in which the percentage of the global energy used in cities is increasing considerably. Biomass is a resource that is present in a variety of different materials: wood, sawdust, straw, seed waste, manure, paper waste, household waste, wastewater, etc. Biomass resources have traditionally been used, and their use is becoming increasingly important due to their economic potential, as there are significant annual volumes of agricultural production, whose by-products can be used as a source of energy and are even being promoted as so-called energy crops, specifically for this purpose. The main objective of this work was to analyze the state of research and trends in biomass for renewable energy from 1978 to 2018 to help the research community understand the current situation and future trends, as well as the situation of countries in the international context, all of which provides basic information to facilitate decision-making by those responsible for scientific policy. The main countries that are investigating the subject of biomass as a renewable energy, as measured by scientific production, are the United States, followed by China, India, Germany and Italy. The most productive institutions in this field are the Chinese Academy of Sciences, followed by the National Renewable Energy Laboratory, Danmarks Tekniske Universitet and the Ministry of Education in China. This study also identifies communities based on the keywords of the publications obtained from a bibliographic search. Six communities or clusters were found. The two most important are focused on obtaining liquid fuels from biomass. Finally, based on the collaboration between countries and biomass research, eight clusters were observed. All this is centered on three countries belonging to different clusters: USA, India and the UK.

Keywords: biomass; carbon; renewable energy; bioenergy; bibliometric research

1. Introduction

The world's population continues to grow at a high rate, such that today's population is twice that of 1960, and it is projected to increase further to 9 billion by 2050 [1]. Forecasting models suggest that developing countries will account for 99 per cent of this population increase, with population growth of 50 per cent in urban areas [2,3]. This situation has brought about a situation in which the percentage of global energy used in cities is increasing considerably. In the early 1990s, cities consumed less than half of the total energy produced, while they currently use two-thirds of the worldwide energy [4]. This means that the share of urban energy use in the global energy mix is growing at a higher rate than the global share of the urban population. Although cities continue to use fossil fuels as the main source of energy, energy sustainability is becoming a key political solution to mitigate problems related to climate change [5]. Indeed, cities represent 70% of the total emissions of CO_2 caused by humans [6], being one of the largest contributors to climate change. In addition, cities face devastating effects from climate change. Approximately 70% of cities are already coping with the effects of climate change. Since 90% of all urban areas are coastal, the damage caused by rising sea levels is expected to increase, with some cities in developing countries being particularly vulnerable. The increase in urban energy consumption has also led to an increase in urban air pollution. According to the World Health Organization (WHO), 90% of the inhabitants of urban areas are subject to environmental pollution levels that exceed the recommended limits [7].

Biomass refers to all organic matter existing in the biosphere, whether of plant or animal origin, as well as those materials obtained through their natural or artificial transformation [8–10]. Biofuels derived from biomass include firewood, wood shavings, pellets, some fruit stones such as olives and avocados, as well as nutshells. Of these, cut and chopped firewood is the least processed, and is usually burned directly in domestic appliances such as stoves and boilers. The chips come from the crushing of biomass both agricultural and forest, with their size being variable depending on the manufacturing process from which they are derived, or the transformation process that they have undergone. Finally, pellets are the most elaborate biofuel, and consist of small cylinders 6 to 12 mm in diameter and 10 to 30 mm in length that are obtained by pressing biofuels with binders. Pellets are used especially in fuels with a low energy/volume ratio [11,12]. Fruit stones and seeds, as well as fruit husks, though used to a lesser extent than other standardized fuels such as fuelwood, wood chips and pellets, also represent an increasingly used solid biofuel. Indeed, it has been shown that mango stone, peanut shell and sunflower seed husk have a high energy potential, with a Higher Heating Value (HHV) similar to other commercialized biofuels [13–15]. This fact, together with the increasing worldwide production of these by-products, makes them especially attractive for thermal energy generation, as well as to reduce CO_2 emissions. Biomass is present in a variety of different materials: wood, sawdust, straw, seed waste, manure, paper waste, household waste, wastewater, etc. [16].

Renewable energy for heating comes either from decentralized equipment in buildings or from centralized generation and its further distribution [17]. Decentralized biomass boilers are an emerging technology in constant development [18]. Biomass is a carbon-neutral energy source, since the biomass during its growth absorbs CO_2 that is then released into the atmosphere during its combustion, with a zero-net balance of CO_2 emissions [19]. However, large amounts of thermal energy are wasted in power generation and in many manufacturing processes. Cogeneration is the most widely used technology to reuse lost heat, generating useful heat as well as electrical energy. Combined Heat and Power plants (CHP) simultaneously produce electricity and heat for use in industrial, trade or residential contexts. Industry consumes all the heat and electricity it needs, and the excess electricity is fed into the grid and is consumed mostly in the local environment [20,21]. On the other hand, district heating and cooling networks are a highly effective way to integrate natural resources such as industrial and agricultural biomass, while increasing energy efficiency. Distributed energy systems consist of a network of underground insulated pipes, connected to a thermal or cold heat plant, through which hot or cold water is pumped to several buildings within a district [14].

Due to the wide availability of biomass worldwide, mainly because it can be obtained as a by-product of many industrial and agricultural processes, biomass represents a growing renewable energy source with high growth potential [22]. One of the main characteristics of biomass that makes it suitable as an energy source is that through direct combustion it can be burned in waste conversion plants to produce electricity [23] or in boilers to produce heat at industrial and residential levels [24]. However, it must be borne in mind that direct combustion of biomass is not always feasible in existing facilities, and that in many cases it is necessary to carry out physical-chemical or biological treatments to adapt it to the quality of conventional fuels. Biomass District Heating (BDH) is a very effective system for the integration of natural energy resources within urban environments, achieving on the one hand a 100% reduction in CO_2 emissions compared to fossil fuels, and on the other hand an increase in energy efficiency due to the lower cost of biofuels. Biomass exists in a variety of different materials: wood, sawdust, straw, seed waste, manure, paper waste, household waste, wastewater, etc. [25]. The characteristics of some materials allow them to be used as fuels directly; however, others require a series of pretreatments, which require different technologies before they can be used.

Biomass has its flaws, but also its strengths. Among its great benefits is the forest use of the territory, which would also serve to clean the forest and thus prevent forest fires, and the ability to generate jobs. Biomass generates continuous employment such as the extraction of raw materials from the countryside and the bush [14]. Nowadays, the use of biomass as biofuel represents a field of great interest to the scientific community. Table 1 presents a synthesis of the ways of approach from the literature depending of the type of biomass.

Table 1. Main researches on biomass as biofuel during the last ten years.

Year	Biomass Type	Biomass Origin	Analysis Type	Reference
2018	Walnut shell	Agriculture residue	Ultimate analysis	[17]
2013	Wood bark	Forests	Ultimate analysis	[26]
2017	Wheat straw	Agriculture residue	Ultimate analysis	[27]
2018	Peanut shell	Industrial residue	Ultimate analysis	[15]
2018	Mango stone	Industrial residue	Ultimate analysis	[13]
2016	Avocado Stone	Industrial residue	Ultimate analysis	[5]
2017	Wood	Forests	Ultimate analysis	[27]
2013	Olive stone	Industrial residue	Ultimate analysis	[28]
2005	Almond shell	Industrial residue	Ultimate analysis	[29]
2018	Sun flower seed husk	Industrial residue	Ultimate analysis	[24]
2015	Pine pellets	Forests	Ultimate analysis	[30]
2019	Palm oil Kernel Shell	Industrial residue	Proximate and elemental analysis	[31]
2018	Corn cob waste	Industrial residue	Ultimate analysis	[32]

At present, a large part of the research has been focused on environmentally friendly and sustainable energy from biomass to supplement conventional fossil fuels [33]. The main objective of this work was to analyze the state of research and trends in biomass for renewable energy from the last 40 years (from 1978 to 2018) to help the research community understand the future trends, as well as the situation of a country in the international context, all of which provides basic information to facilitate decision-making by those responsible for scientific policy.

2. Research Approach

The analysis of scientific publications constitutes a fundamental step within the research process and has become a tool that allows us to qualify the quality of the process generating the knowledge and the impact of this process on the environment. Bibliometrics is a discipline of scientometrics and provides information on the results of the research process, its volume, evolution, visibility and structure. In this way, it is possible to assess scientific activity and the impact of both research and sources [34].

Bibliometric studies provide an interesting overview of a country's own scientific activity, as well as its situation in the international context, all of which provides basic information to facilitate decision-making by those responsible for scientific policy.

In this study, a complete search of Elsevier's Scopus database was conducted using the subfields (TITLE-ABS-KEY (biomass) AND TITLE-ABS-KEY (renewable AND energy)) to identify publications addressing the subject of publications from 1978 to 2018 that referred to biomass as renewable energy.

Scopus is a bibliographic database of documents from scientific journals. It contains information relating to more than 35,000 titles from all areas. It includes, in addition to journals, monographic series, conference proceedings, books (emptied at book and chapter level) and patents. Patents are vacated from five official offices (WIPO, EPO, United States, Japan and United Kingdom), offering more than 27 million [35].

Temporal coverage dates back to 1996 but can sometimes be traced back to 1823.

In addition to providing bibliographic information, Scopus offers bibliometric tools that measure the performance of publications and authors, based on the count of citations received for each article.

Once the results of the Scopus search related to biomass as a renewable energy were obtained, this study carried out an analysis of the types of documents, language of the documents, scientific production and its trend, main scientific institutions with scientific productions related to the subject, collaborations between countries and main authors in the subject, and the evolution in the use of key words. Another key aspect of this research was the identification of scientific communities using Vosviewer software (http://www.vosviewer.com/). Vosviewer is free software that allows you to build and visualize bibliometric networks from data obtained from bibliometric searches of important databases such as Scopus [36]. Figure 1 shows a scheme of the methodology used.

The methodology used in this study contained the following steps:

1. Global search for information. The Scopus database was used to search for information using the following search fields: (TITLE-ABS-KEY (biomass) AND TITLE-ABS-KEY (renewable AND energy)). The search result was a .csv file containing the following information: Authors, Author Ids, Title, Year, Source title, Volume, Issue, Art. No., Page start, Page end, Page count, Cited by, DOI, Link, Document Type, Access Type, Source, EID.
2. Bibliometric data analysis. Each piece of the above data was analyzed and studied separately. For example, it was analyzed who the main authors were that have published on this subject, or what types of documents have been published on this subject (articles, reviews, etc.).
3. Community detection. The community detection of thematic clusters (community or cluster detection) was analyzed with VOSviewer, obtaining maps of international collaboration between different countries and authors, and the research trends using keywords.

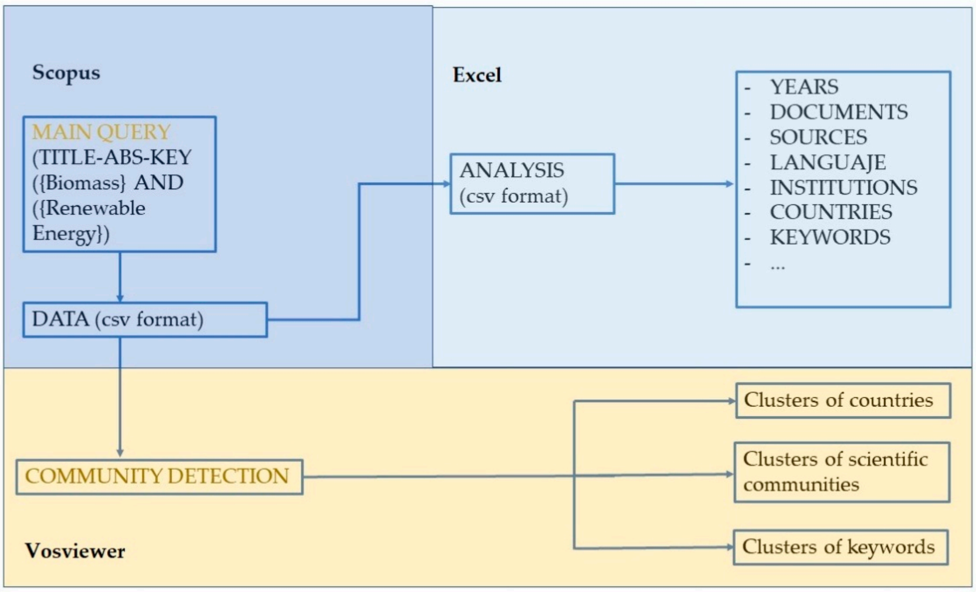

Figure 1. Methodology scheme.

3. Results and Discussion

The number of publications of an institution, area or country is a useful indicator to quantify the scientific activity of these units. Its greatest usefulness is obtained when making comparisons with the activity of other institutions, areas or countries, since it is necessary to have a frame of reference within which to locate our object of study. It is also interesting to monitor scientific production over time.

3.1. Type and Language of Publications

17,274 documents were obtained from the search carried out considering various fields and types of documents for the period 1978–2018. According to the different types of publications, most of the research works were Articles (59.0%), followed by Conference Papers (23.2%) and Reviews (9.4%). In contrast, the smallest numbers of documents were obtained for Notes (1.2%), Books (0.9%) and Short Surveys (0.6%). Figure 2 shows the different types of documents related to biomass as renewable energy during the period 1978–2018.

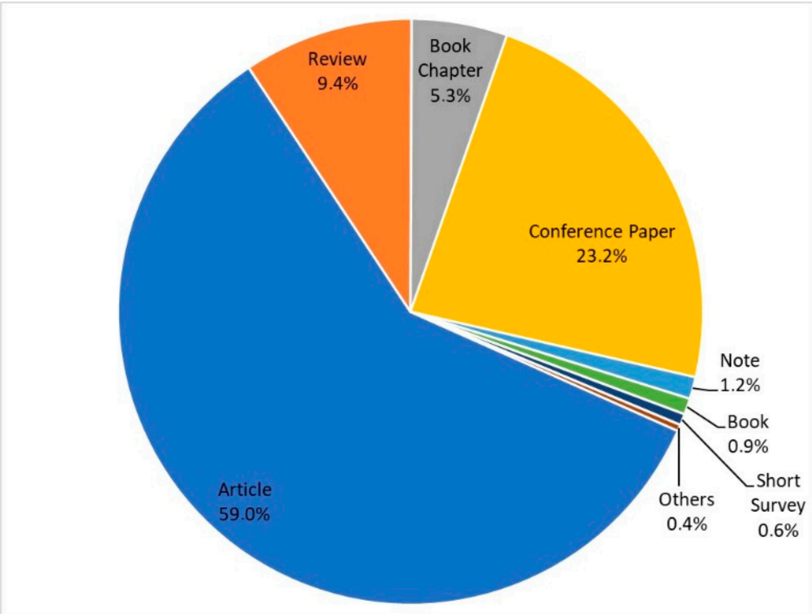

Figure 2. Distribution of different types of publications during the period 1978–2018.

In reference to the type of languages used in the publications obtained from the search, most of the documents were published in English in international journals, followed by Chinese (2.04%), German (0.30%) and Spanish (0.27%). Figure 3 shows the percentage of the different languages in which the different documents obtained from the bibliometric analysis have been published.

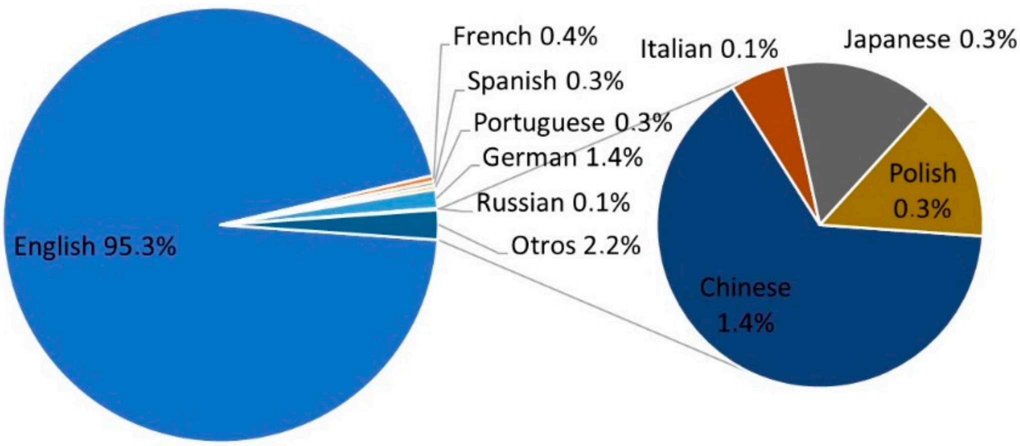

Figure 3. Language of publications for the period 1978–2018.

3.2. Characteristics of Scientific Production for the Period 1978–2018

Figure 4 shows the trend in scientific production over the last 40 years. As can be seen, during the first 30 years, there is no significant growth in scientific production on the use of biomass as renewable energy. In 2008 there is a very important growth in publications due to oil peaking at over $136 a barrel in June 2008, and it has never been that high since then. Therefore, the reason was the high price of oil followed by a widespread economic downturn.

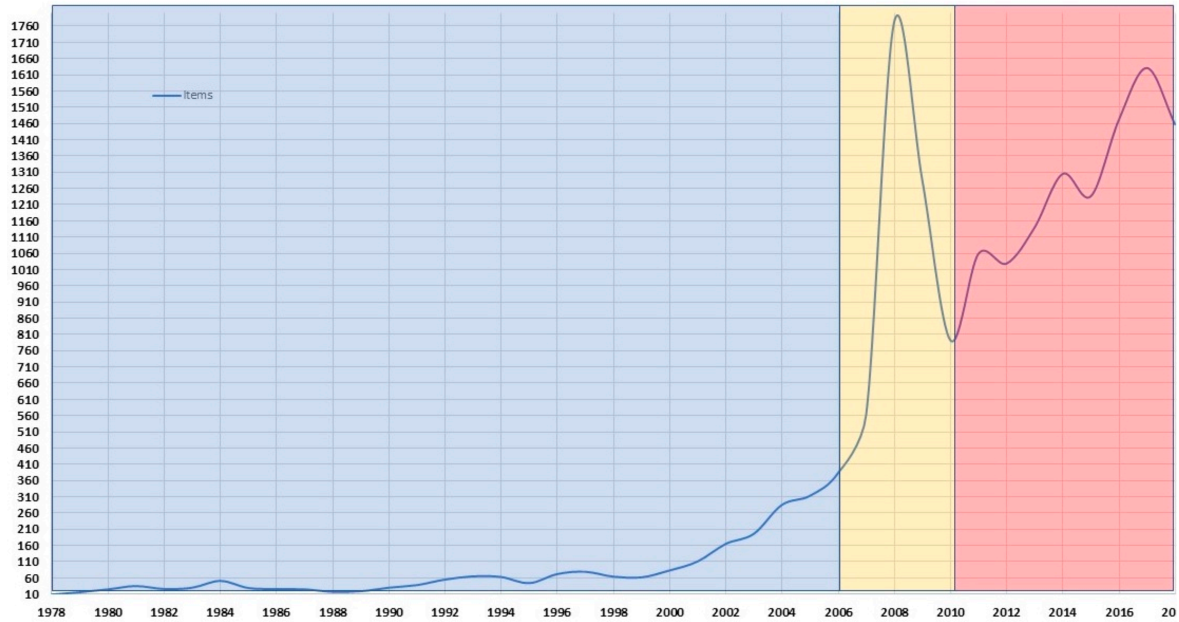

Figure 4. Trend in biomass as renewable energy publications during the period 1978–2018.

3.3. Worldwide Distribution of Publications

Figure 5 shows world scientific production by country of origin. According to the number of publications each country has an assigned color that goes from red, which indicates a greater number of publications, to gray, which indicates the non-existence of publications. The United States is the country with the highest number of publications (3318) in this field, followed by China (1514), India (1165), Germany (1137) and Italy (993). From this, it can be concluded that the use of biomass as renewable energy in industrialized countries is a key element in achieving sustainable development. Within industrialized countries, governments promote energy policies with the aim of reducing greenhouse gases and consequently global warming.

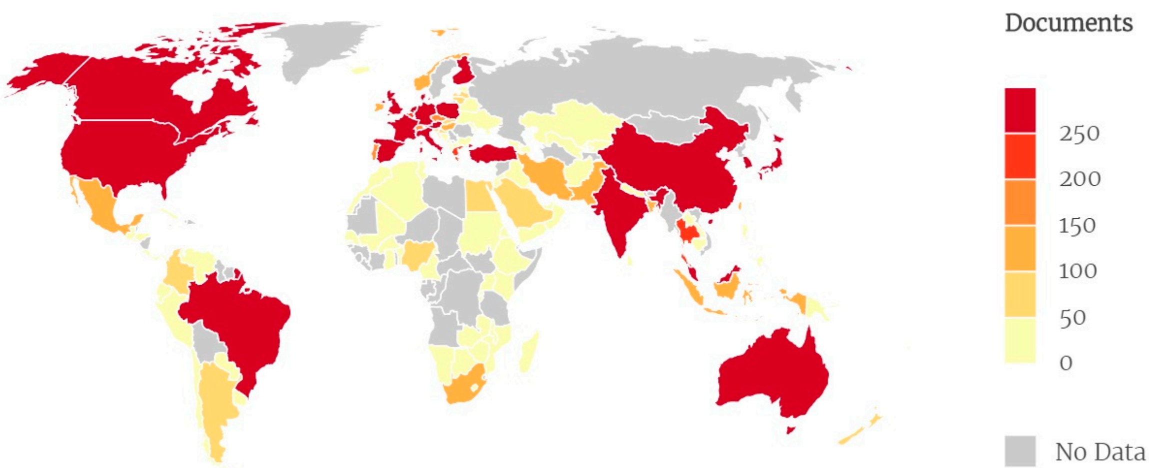

Figure 5. World scientific production in biomass as renewable energy by country of origin.

In the United States, a climate change plan called the 'Clean Power Plan' stands out. It includes the lines that the USA Environmental Protection Agency (EPA) announced in September 2013, aiminged to reduce emissions by 30% by 2030. This USA Clean Energy Plan set carbon pollution standards for power plants, states and utilities for the first time, with the flexibility that they need to meet their standards.

Figure 6 represents the evolution of the number of documents from the 5 countries with the highest scientific production related to biomass as renewable energy. It is possible to observe how in 2008 these 5 industrialized countries regain their scientific production on this subject due to the sustainability policies carried out by the different governments.

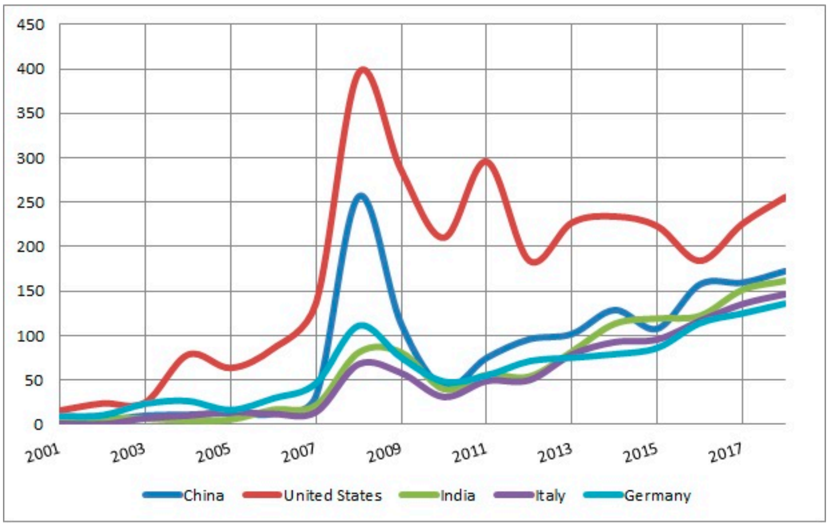

Figure 6. Trends in publications on renewable energy in urban areas during the last 18 years for the top five countries.

Figure 7 represents the existing network of collaboration between the countries of different authors sharing the same publication. This figure was extracted from the software VOSviewer v.1.6.6., which uses the information obtained from the Scopus search and which can be downloaded as a .csv file.

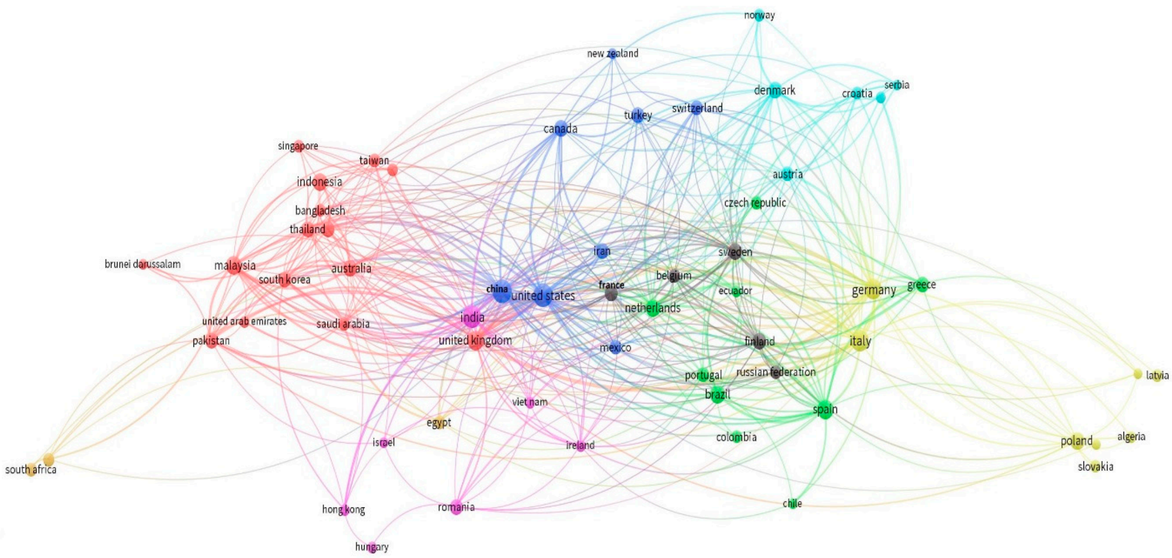

Figure 7. Collaborative work between countries.

From the collaboration between countries and biomass research, eight clusters are observed, see Figure 7 and Table 2. All this is centralized around three countries belonging to different clusters: USA, India, and the UK. The red cluster is the most important, and is led by the UK; as can be seen, it is composed of its traditional area of political and economic influence, to which Japan joins. The green cluster is the second most important and consists mainly of Latin American countries. The blue cluster is led by the USA and is in close relationship with China and other North American countries such as Canada and Mexico. The yellow cluster is led by Germany and is mainly related to Eastern European countries. With less importance would be the Central European clusters (in the color Turquoise), Scandinavia-Russia (in the color Grey), and in Orange that of some African countries. It can therefore be deduced that there are two forms of grouping: the first is based on the influence or economic relations between groups of countries, which in this scenario would be the four most important clusters; and the second would be in terms of the type of biomass they may have, based on their geographical location or climatic conditions, which in this situation would be the last three clusters.

Table 2. Country communities detected in the topic biomass as renewable energy.

Cluster	Color	Countries	Geographic Areas	%
1	Red	Australia-Bangladesh-Brunei Darussalam-Indonesia-Japan-Malaysia-Pakistan-Philippines-Saudi Arabia-Singapore-South Korea-Taiwan-Thailand-United Arab Emirates-United Kingdom	Asia-Arabian Peninsula-UK	24.59
2	Green	Brazil-Chile-Colombia-Czech Republic-Ecuador-Greece-Netherlands-Portugal-Spain	Latin America-Spain and Portugal	14.75
3	Blue	Canada-China-Iran-Mexico-New Zealand-Switzerland-Turkey-United States	North America-China	13.11
4	Yellow	Algeria-Germany-Italy Latvia-Lithuania-Poland-Slovakia-Ukraine	Eastern Europe-Germany	13.11
5	Purple	Hungary-India-Ireland-Israel-Romania-Viet Nam	India	11.48
6	Turquoise	Austria-Croatia-Denmark-Norway-Serbia-Slovenia	Central Europe	9.84
7	Grey	Belgium-Finland-France-Russian Federation-Sweden	Scandinavia-Russia	8.20
8	Orange	Egypt-Nigeria-South Africa	Africa	4.92

3.4. Institutions Distribution of Publications

Table 3 shows the ten institutions with the highest scientific production in the field of biomass as renewable energy, as well as the keywords most used by these institutions.

In the first place, the Chinese Academy of Sciences, with 267 documents, stands out, followed by the National Renewable Energy Laboratory with 180, Danmarks Tekniske Universitet with 136, Ministry of Education China with 116, University of Sao Paulo with 112, USDA Agricultural Research Service, Washington DC with 108, OAK Ridge National Laboratory with 107, Wageningen University and Research Centre with 104, Sveriges Lanbruksuniversitet with 97 and Imperial College London with 84. It should be noted that the keyword most used by most of these institutions is Biofuel, ranking first in five of the ten institutions.

With respect to the type of research carried out, it can be seen how Chinese institutions focus on solid fuels, perhaps as an alternative to coal, while US and Brazilian institutions focus on liquid fuels such as ethanol and how it is obtained from crops, especially corn (Zea Mays) in the USA and sugarcane in Brazil. A third line of research is that of CO_2 emissions (carbon dioxide), where they focus on reducing emissions and energy policy, in this case we have the Danmarks Tekniske Universitet and the Imperial College London.

Table 3. Scientific production and keywords used by the ten most important international institutions.

Institution	Country	Documents	Main Keywords Used		
			1	2	3
Chinese Academy of Sciences	China	267	Biological Materials	Gasification	Carbon
National Renewable Energy Laboratory	USA	180	Biofuel	Ethanol	Cellulose
Danmarks Tekniske Universitet	Denmark	136	Carbon Dioxide	Ethanol	Biofuel
Ministry of Education China	China	116	Carbon	Biofuel	Biological Materials
Universidade de Sao Paulo—USP	Brazil	112	Ethanol	Biofuel	Sugarcane
USDA Agricultural Research Service, Washington DC	USA	108	Crops	Zea Mays	Feedstocks
OAK Ridge National Laboratory	USA	107	Biofuel	Bioenergy	Lignin
Wageningen University and Research Centre	Netherlands	104	Bioenergy	Biological Materials	Nonhuman
Sveriges Lanbruksuniversitet	Sweden	97	Forestry	Bioenergy	Fuels
Imperial College London	England	84	Bioenergy	Energy Policy	Carbon Dioxide

3.5. Subject Categories and Journals Obtained from Scopus

The distribution of publications by thematic areas was also obtained from the bibliometric analysis using the Scopus database. Figure 8 shows that the highest percentage of documents were in the area of Energy (23.4%), followed by Environmental sciences (18.0%) and Engineering (12.4%). Areas such as Earth and Planetary Sciences (2.4%), Materials Science (2.4%) or Immunology and Microbiology (2.1%) were found to a lesser extent. The "Others" area includes unspecified subject areas.

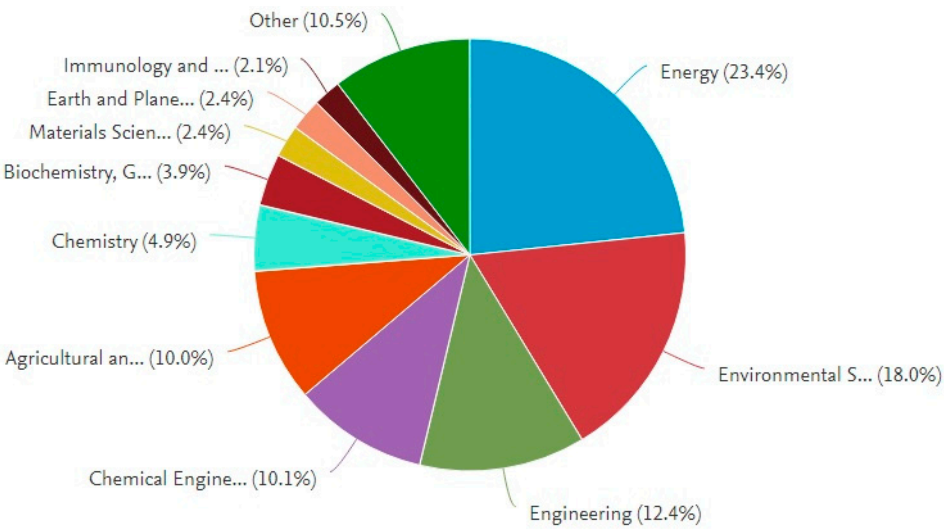

Figure 8. Thematic areas of publications obtained from the Scopus search.

Table 4 shows the thematic areas of publications obtained from the Scopus search.

The assessment of the impact of papers through the citations they receive is not an immediate measure but can only be applied several years after the publication of the documents. To avoid this problem, an alternative method was introduced for the counting of citations received by papers, consisting of attributing a weight to publication journals based on the average number of citations received by their papers. Since journals that publish more articles are more likely to be cited, the so-called journal impact factor was introduced, which normalizes the number of citations according to the size of the journal.

The 11 main journals that have published in the search field performed with the Scopus database are shown in Table 5.

Table 4. Main thematic areas according to the number of publications obtained.

Subject Area	Number of Publications
Energy	7714
Environmental Science	5926
Engineering	4102
Chemical Engineering	3324
Agricultural and Biological Sciences	3297
Chemistry	1625
Biochemistry, Genetics and Molecular Biology	1288
Materials Science	803
Earth and Planetary Sciences	791
Immunology and Microbiology	689
Social Sciences	675
Physics and Astronomy	627
Computer Science	502
Business, Management and Accounting	452
Mathematics	314
Economics, Econometrics and Finance	296
Medicine	181
Multidisciplinary	167
Decision Sciences	83
Pharmacology, Toxicology and Pharmaceutics	70
Others	74

Table 5. SJR, H-Index and JCR impact factor of principal international journals.

Journals	Q	SJR	H-Index	JCR	Total Docs (2017)	Total Docs (3 Years)	Total Refs.	Total Cites (3 Years)	Cites/Doc (2 Years)	Country
Renewable and Sustainable Energy Reviews	Q1	3.036	193	9.184	1439	3,330	152,276	34,869	10.03	The Netherlands
Biomass and Bioenergy	Q1	1.235	146	3.358	257	1126	11,100	4406	3.59	United Kingdom
Bioresource Technology	Q1	2.029	229	5.807	1638	4644	65,023	29,041	6.15	The Netherlands
Renewable Energy	Q1	1.847	143	4.900	1039	2679	38,958	14,269	5.40	United Kingdom
Energy	Q1	1.990	146	4.968	1951	4290	86,123	23,896	4.80	United Kingdom
Energy Policy	Q1	1.994	159	4.039	713	1636	38,575	8086	4.27	United Kingdom
Applied Energy	Q1	3.162	140	7.900	1,775	4112	87,103	34,541	8.30	United Kingdom
Energy Procedia	-	0.524	56	-	5305	7546	82,542	10,772	1.32	United Kingdom
International Journal of Hydrogen Energy	Q1	1.116	173	4.229	3091	6705	129,956	27,353	4.13	United Kingdom
Journal of Cleaner Production	Q1	1.467	132	5.651	2,57	4124	143,511	23,583	5.34	The Netherlands
Energy Conversion and Management	Q1	2.537	147	6.377	1079	3123	49,900	21,286	6.84	United Kingdom

First place goes to the journal “Renewable and Sustainable Energy Reviews” with an H-index of 193 and a JCR impact factor of 9.184, followed by “Biomass and Bioenergy” with an H-Index of 143 and a JCR impact factor of 3.358, and third place goes to "Bioresource Technology" with an H-Index of 229 and a JCR impact factor of 5.807.

3.6. Detection of Scientific Communities and Trends in the Use of Keywords

This study also carried out an analysis of the most prominent authors in the fields of renewable energy production with biomass. Figure 9 and Table 6 show the scientific production of the 4 main authors on this subject in the last ten years. Omer, A.M. stands out in this field with 122 publications since 2008. This researcher has an h-index of 15, followed by Pari, L. with an h-index of 14, Kaltschmitt, M. with an h-index of 17 and Tippayawong, N. with an h-index of 15.

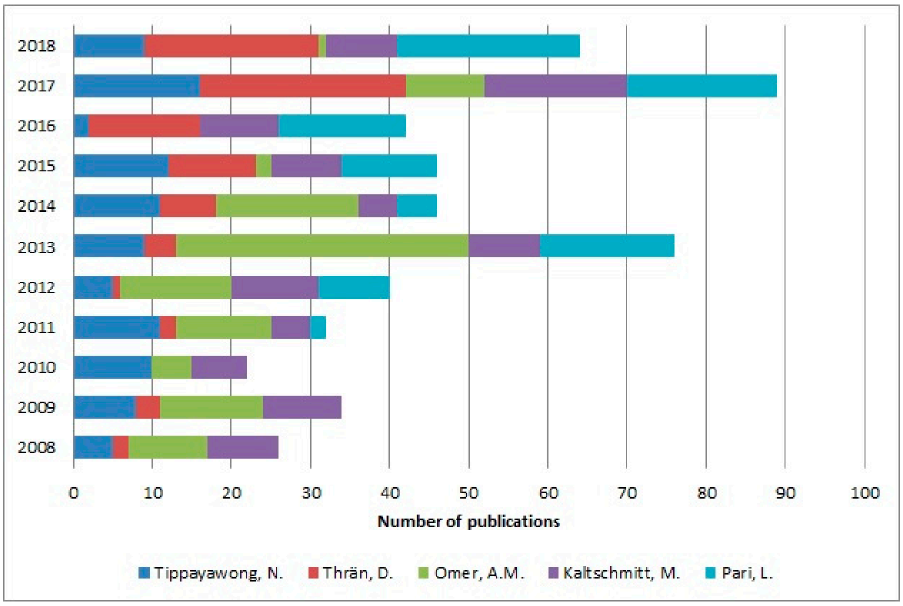

Figure 9. Bar chart of the main authors' publications in the last ten years.

Table 6. Evolution of the main authors' publications over the last ten years.

Year	Tippayawong, N. (Thailand)	Thrän, D. (Germany)	Omer, A.M. (United Kingdom)	Kaltschmitt, M. (Germany)	Pari, L. (Italy)	TOTAL
2008	5	2	10	9	0	26
2009	8	3	13	10	0	34
2010	10	0	5	7	0	22
2011	11	2	12	5	2	32
2012	5	1	14	11	9	40
2013	9	4	37	9	17	76
2014	11	7	18	5	5	46
2015	12	11	2	9	12	46
2016	2	14	0	10	16	42
2017	16	26	10	18	19	89
2018	9	22	1	9	23	64
TOTAL	98	92	122	102	103	517

A scientific community can be defined as a set of nodes that are more densely connected to each other than to the rest of the network. Scientific communities tend to have a central nucleus cohesive with peripheral spheres, which are the weakest links as it moves away from the nucleus. The central nucleus would be formed by the most significant elements of the community. Scientific communities are usually groups that relate to members of groups from other communities [37].

Clustering scientific publications is an important problem in current research. Identifying communities or clusters is a topic of great current scientific interest, making it possible to identify and to quantify the existing relations of collaboration between the authors of diverse institutions and areas of knowledge. The detection of communities has been successfully applied in fields such as medicine [38], or energy [39]. The VOS algorithm mapping technique implemented in the software VOSviewer [40] was used to identify and to quantify the collaboration between authors. VOSviewer's algorithm aims at locating the items in a low-dimensional space so that the distance between two items is an accurate indicator of their relatedness.

Figure 10 shows the detection of scientific communities of authors using the VOSviewer software. This figure shows the relationships between the main researchers in the field of biomass as renewable energy. Asian researchers with strong research connections between them stand out due to both the language and the proximity of their institutes. Cluster 1 (red) is the biggest in terms of number of members with ten authors, followed by cluster 2 (green) with eight authors. The top high-yield authors formed their own cooperative team. The largest node is Zhang, X., who has 20 publications and 8 neighbors, followed by Wang, Y., who has 19 publications and 7 members.

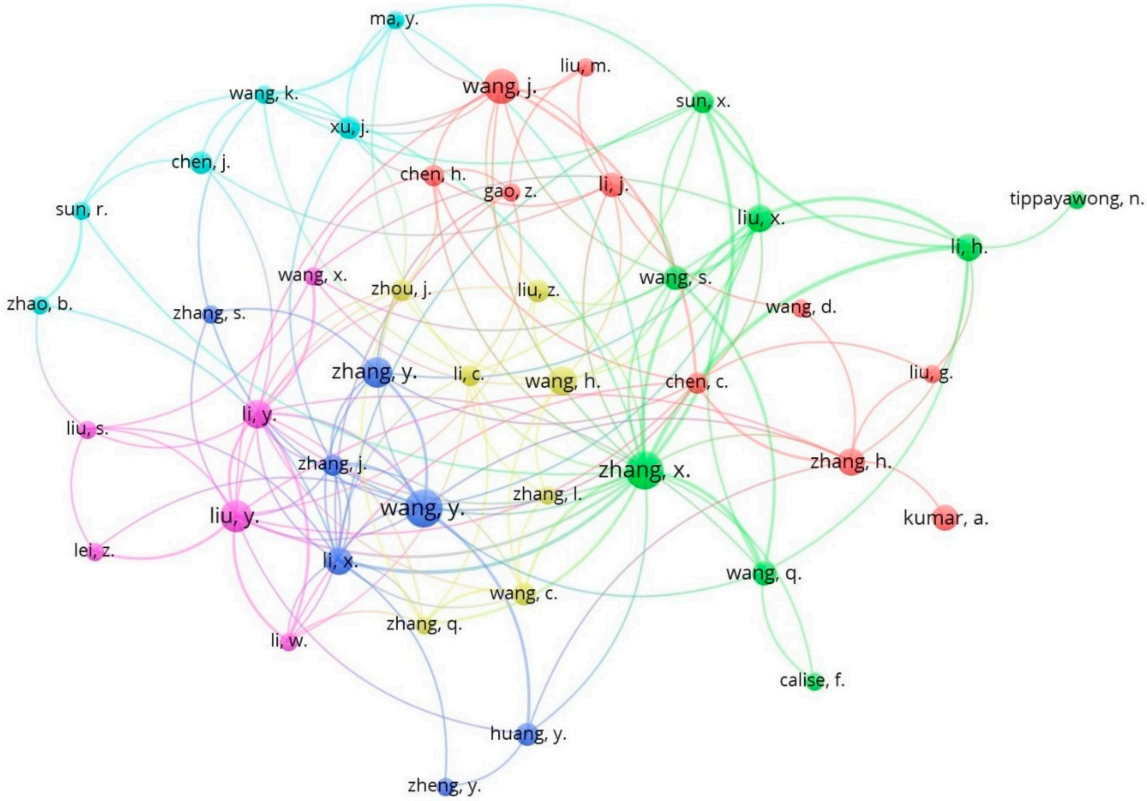

Figure 10. Scientific communities of authors related with biomass as renewable energy.

Another important analysis to carry out is that of the key words used in the publications related to the topic of study. During the last 40 years, 17,254 documents have been found, among which the keyword Biomass, appearing in 9753 items, stands out, followed by Renewable Energy Resources (4900 items), and in third place Renewable Energy (2511 items). Table 7 shows the 40 most significant keywords in the last four decades.

Table 7. Forty main keywords used in publications.

Order	TERM	Items	%
1	Biomass	9753	17.29
2	Renewable Energy Resources	4900	8.69
3	Renewable Energy	2511	4.45
4	Renewable Resource	2296	4.07
5	Renewable Energies	2276	4.03
6	Biofuels	1691	3.00
7	Carbon Dioxide	1500	2.66
8	Fossil Fuels	1478	2.62
9	Bioenergy	1353	2.40
10	Biological Materials	1350	2.39
11	Energy Policy	1254	2.22
12	Sustainable Development	1241	2.20
13	Gasification	1166	2.07
14	Renewable Energy Source	1108	1.96
15	Solar Energy	1099	1.95
16	Greenhouse Gases	1084	1.92
17	Ethanol	1050	1.86
18	Carbon	999	1.77
19	Fuels	991	1.76
20	Forestry	987	1.75
21	Biogas	983	1.74
22	Wind Power	945	1,68
23	Energy Efficiency	943	1,67
24	Biomass Power	910	1,61
25	Nonhuman	902	1,60
26	Priority Journal	874	1.55
27	Environmental Impact	872	1.55
28	Combustion	860	1.52
29	Energy Utilization	859	1.52
30	Alternative Energy	803	1.42
31	Cellulose	802	1.42
32	Pyrolysis	780	1.38
33	Hydrogen	773	1.37
34	Gas Emissions	739	1.31
35	Agriculture	736	1.30
36	Fermentation	719	1.27
37	Crops	716	1.27
38	Climate Change	715	1.27
39	Energy Resource	715	1.27
40	Economics	684	1.21

As a preliminary step to carrying out searches, you must know, for example, prominent authors in the subject matter of the search, keywords related to the subject, type of publications dedicated to that subject and institutions, events in which the subject is dealt with, and institutions and organizations related to it, so that you can locate authors, books, journals, proceedings, etc. that may be of interest. Therefore, the analysis of keywords in scientific publications is of great importance to knowing the research trends and their follow-up. From this study, the existence of different versions for a keyword can be observed, depending on the way each author expresses himself or herself. For example, looking at Table 6, similar concepts can be observed written in different ways, such as: 'Renewable Energy', 'Renewable Resource', 'Renewable Energy Resources', 'Renewable Energies'. In Figure 11, a cloud of words is shown where the size of the letters represents the importance of the keyword according to the number of items in which it appears.

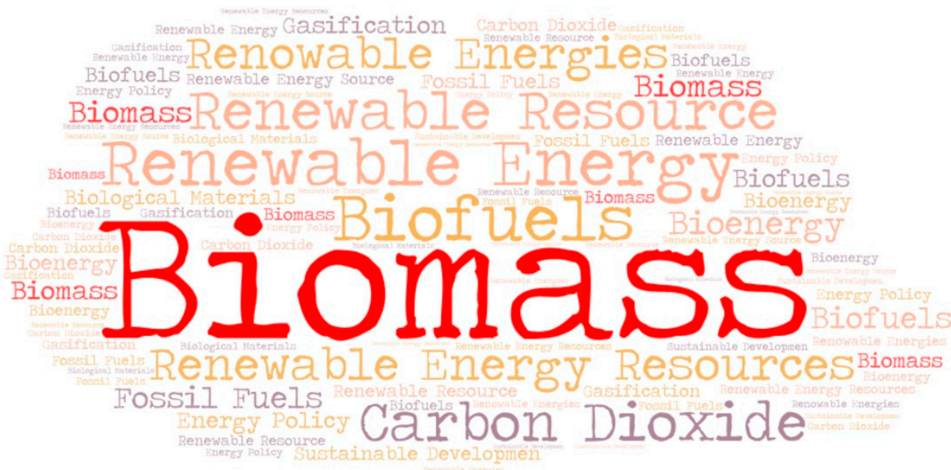

Figure 11. Cloud word of main keywords related to biomass as renewable energy.

Figure 12 shows the evolution over time of the 5 keywords that appear in the largest number of publications related to the use of biomass as renewable energy. It can be observed that in 2008 the use of these keywords exhibited a great increase, possibly due to the entry into force of the Kyoto Protocol in 2008. The objective of the Kyoto Protocol was to reduce global greenhouse gas emissions by 5.2% compared to 1990 levels over the period 2008–2012 [41]. It is the main international instrument for tackling climate change. To this end, the Protocol contains targets for industrialized countries to reduce emissions greenhouse gases.

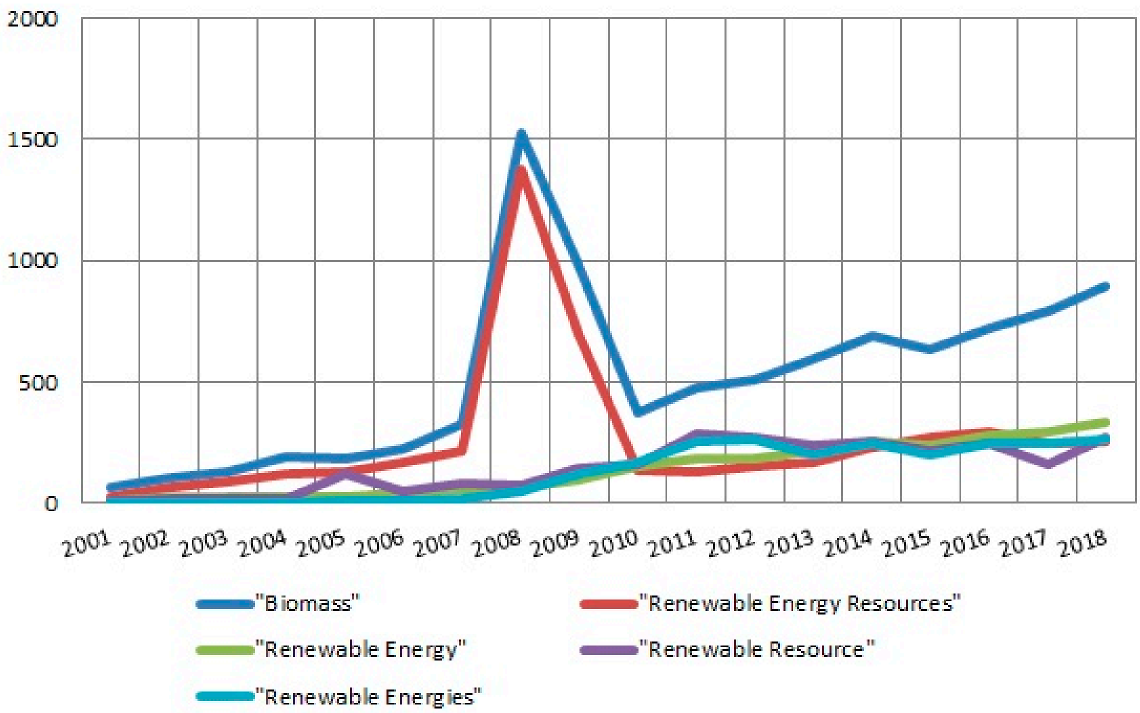

Figure 12. Evolution of the top five keywords in the period 2001–2018.

Currently, the trend in the growth of these keywords continues due to the sustainability policies carried out by governments and supported by the fight against climate change, which has become a global issue of interest.

Figure 13 shows a network map of the co-occurrence of the main keywords used by authors of publications related to the use of biomass as renewable energy. The VOS algorithm mapping technique implemented in the software VOSviewer was used to obtain Figure 13. Colors represent the division between keywords according to the field in which they have been used, the size of the circles shows how often a term has been used, and the lines connecting the different circles indicate the link between keywords through articles and other publications. In this study, 'Biomass', Renewable Energy Resources', 'Renewable Energy', 'Renewable Resource' and 'Renewable Energies' are the most commonly used words, although they are not the ones that are most related to other key words such as 'Carbon' or 'Bioenergy'.

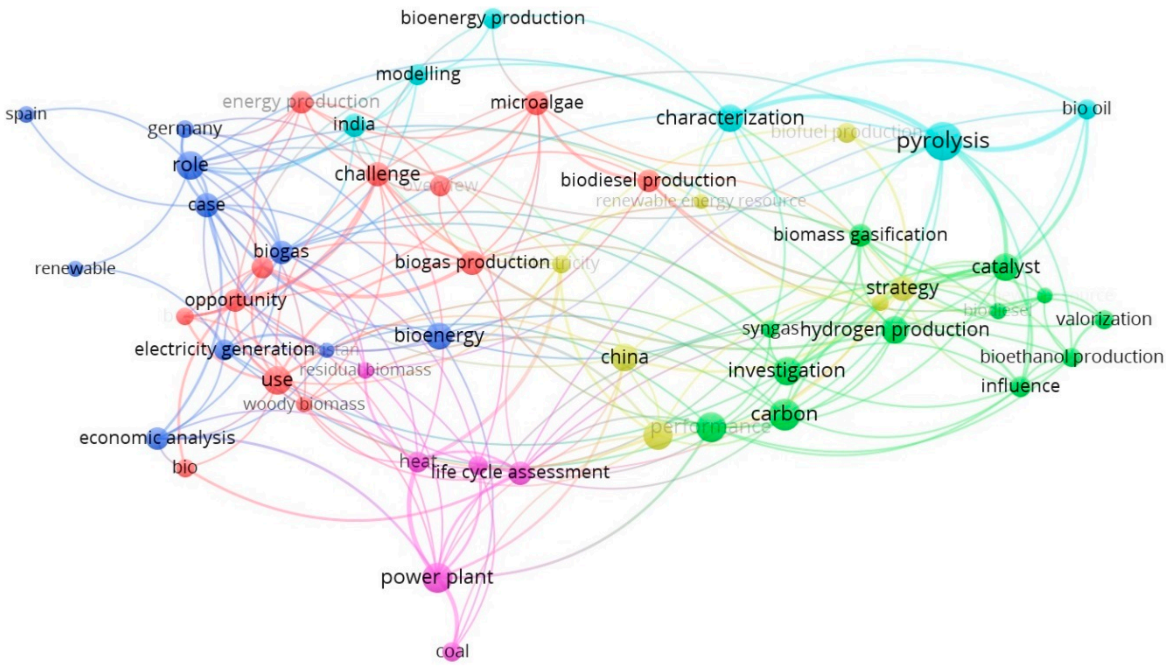

Figure 13. Co-occurrence keywords: clusters.

Biofuels are used in all three states of matter, i.e., solid, liquid and gaseous. In solid state are basically wood and chips, charcoal and pellets [42]. In liquid form, bioethanol and biodiesel stand out. In addition, in the gaseous state, there is biogas (methane, hydrogen and nitrogen, above all), normally obtained either by anaerobic fermentation of microbiological origin, or by gasification (partial oxidation of biomass at high temperature, about 1400 °C, without combustion) [43]. Table 8 shows the principal characteristics of each cluster detected in Figure 13. As can be seen, 6 communities or clusters were found. The two most important are focused on obtaining liquid fuels from biomass. The red cluster is mainly focused on the production of biodiesel, both in the classic ways of obtaining by transesterification of oils from seeds (especially rapeseed and sunflower) or from vegetable oil residue of industrial processes. This includes new sources of fat or raw materials such as microalgae [44,45] or insects [46], and was found as a keyword for the country of Brazil [47,48]. The second cluster, the green one, is more focused on bioethanol, produced either from sugars from crops such as sugar cane [49] or beet [50], or from starches from crops such as potatoes, corn or other cereals. The other line of work in this cluster is the production of hydrogen or other hydrocarbons from biomass gasification [23]. The third cluster is devoted to two fundamental issues, the generation of electricity from biomass and the production of biogas, the latter produced from livestock waste (slurry) [51], sewage sludge [52], urban solid waste [53], agricultural waste [54] and industrial organic waste [55]. Given the diversity of origins in the production of biogas it is logical to find key words from countries as different in customs such as: Germany, Pakistan and Spain. The fourth yellow cluster focuses on China and the assessment of its resources for sustainable development [56]. Finally, we find clusters 5 and 6, which are the smaller ones. The purple cluster 5 focuses on the Power Plant and the alternative to the Coal, as it has topics related to environmental impact [57]. Cluster 6, turquoise in color, revolves around pyrolysis and India as a leading country [58].

Table 8. Main keywords used by the communities detected in the topic biomass as renewable energy.

Cluster	Color	Main Keywords	Topic	%
1	Red	Biodiesel production-Anaerobic digestion-biogas production-Brazil-challenge-energy production-microalgae-opportunity-overview-use-woody biomass	Biogas-Biodiesel	22.64
2	Green	Bioethanol production-biomass gasification-carbon-catalyst-hydrogen production-influence-investigation-performance-renewable source-syngas-valorization	Bioethanol-Hydrogen Production-Biomass Gasification	22.64
3	Blue	Bioenergy-biogas-economic analysis-electricity generation-Germany-Pakistan-Spain	Biogas-Electricity generation	18.87
4	Yellow	Biofuel production-China-electricity-impact-renewable energy resource-strategy-sustainable development	China	13.21
5	Purple	Coal-environmental impact-heat-life cycle assessment-power plant-residual biomass	Power Plant-Coal	11.32
6	Turquoise	Pyrolysis-Bio oil-bioenergy production-characterization-India-modelling-	Pyrolysis	11.32

4. Conclusions

From this bibliometric analysis it can be concluded that the main countries that investigate the subject of biomass as renewable energy, as measured by its scientific production, are the United States, followed by China, India, Germany and Italy. It follows that large countries in numbers of inhabitants are interested in the use of new renewable energy sources such as the use of biomass.

In reference to the main institutions researching biomass as renewable energy, three are from the USA (National Renewable Energy Laboratory, USDA Agricultural Research Service, Washington DC, OAK Ridge National Laboratory), two from China (Chinese Academy of Sciences, Ministry of Education China), one from Denmark (Danmarks Tekniske Universitet), one from Brazil (Universidade de Sao Paulo—USP), one from Holland (Wageningen University and Research Centre), one from Switzerland (Sveriges Lanbruksuniversitet) and one from England (Imperial College London). Therefore, the main language of publications on this subject are in English (95.3%), followed by Chinese (1.4%). The main journals that publish more items related to biomass as renewable energy are: "Renewable and Sustainable Energy Reviews", "Biomass and Bioenergy" and "Bioresource Technology".

One of the most important issues of this study is the evolution over time of the growing interest in research in the field of biomass as renewable energy.

As can be seen, during the first 30 years there is no significant growth in scientific production on the use of biomass as renewable energy. In 2008 there is a very important growth due to energy policies to encourage the use of renewable energy due to the increase in the price of a barrel of oil.

As for the area in which the different research carried out in the field of biomass is published, the area of Energy stands out (23.4%); this is because most of the research is directed at the use of biomass to produce thermal energy or electrical energy.

This study has also identified communities based on the keywords of the publications and collaboration between countries obtained from the bibliographic search. Six communities or clusters were found. The two most important were focused on obtaining liquid fuels from biomass.

Finally, from the collaboration between countries and biomass research, eight clusters were observed. All this is centered around three countries, belonging to different clusters: USA, India, and the UK. The most important cluster is led by the UK, and as can be seen, it is composed of its traditional area of political and economic influence, to which Japan is joined. The second most important cluster consists mainly of Latin American countries.

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