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Analysis of the world scientific production on fuels, combustion and exhaust emissions

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Abstract

This paper investigates and analyzes the world scientific production on fuels, combustion and exhaust emissions by employing bibliometric techniques based on the Scopus database. The bibliometric analysis was performed for Year, Subject Area, Document Type, Source Title, Affiliation, Country/Territory, Source Type, and keywords. The investigation was focused on five keywords: "fuel", "combustion", "diesel", "gasoline" and ("exhaust gas" OR "exhaust emission").

In all five keywords, a significant increase of the scientific production occurs with time. Engineering is the most productive subject area in all five cases followed by Energy in "fuel", "combustion" and "gasoline" and by Environmental Science in "diesel" and ("exhaust gas" OR "exhaust emission"). Moreover, during the last years Energy and Environmental Science show an increasing trend.

SAE Technical Papers has the highest number of works in all keywords followed by International Journal Of Hydrogen Energy, Combustion And Flame, Fuel, Oil and Gas Journal and Atmospheric Environment in "fuel", "combustion", "diesel", "gasoline" and ("exhaust gas" OR "exhaust emission"), respectively. USA has a leading position, followed by China and Japan in all five cases, except for "diesel" where India instead of Japan possesses the third position. The most productive institution is Chinese Academy of Sciences for "fuel" and "combustion", Tianjin University for "diesel" and "gasoline" and United States Environmental Protection Agency for "exhaust gas" OR "exhaust emission". The keywords of the categories associated with "Air pollution", "Air pollution control", "Engine", "Vehicles" and "Fuels" are the most commonly used in all five cases. The results of this study shows the trends in scientific issues are related to environmental issues "Air pollution" and "Air pollution control" and can help scientists and policy makers to establish future research priorities.

***Keywords*:** fuel, combustion, diesel, gasoline, exhaust gas, exhaust emission, bibliometric analysis, air pollution and air pollution control.

1. Introduction

Energy is a key determinant for the economic and sustainable growth worldwide and there is no country in the world that can live without energy. Fuel is a concentrated source of energy and they release some of their chemical energy as heat when they are burned. Moreover, 96% of the fuels used for the production of energy are used to produce kinetic energy in engines, with gasoline and diesel to be the two principal fuels (39 and 36% respectively)[1]. It is thus clear that the fields of fuels and combustion are closely linked.

However, the large scale combustion of fuels results in a severe degradation of the environment due to continuous exhaust emissions of different pollutants and challenges human health and sustainability. For example, outdoor air pollution causes about 1.3 million annual deaths worldwide[2].

Gasoline engines emit CO, HC and NOx[3-10] and diesel engines emit CO, HC, NOx and particulate matter (PM)[5-12], which are regulated in EU[13-15], but also other non-regulated pollutants[12-13, 15].

In order to increase air quality, different technologies are used to decrease the exhaust emission of pollutants. For example three way catalyst (TWC) is one of the first aftertreatment device used to decrease exhaust pollutants in spark ignition engines[16-19]. Diesel oxidation catalyst (DOC) is applied years later[16, 20-21], while diesel particulate filter technologies are widely used today[10, 16, 22-23]. DeNox technologies are also used, more in stationary than in mobile sources [10, 16, 24].

As a result, there is a high interest worldwide about the fuels (mainly transport fuels) and their combustion and also their impact through harmful pollutants on environmental degradation.

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Bibliometric techniques provide a useful tool to analyze the development of academic publications trend of a particular scientific field. It was firstly introduced by Pritchard[25]and is considered an interesting research method for conducting systematic analysis[26].Bibliometrics are employed to examine various publication characteristics such as authors, academic institutions, countries, journal, scientific fields and help researchers to recognize novel schemes among them [27-29].

However, to the best of our knowledge there is no bibliometric study focus on fuels, combustion and exhaust emissions. Therefore, the current study aims to investigate and analyze the scientific production related to fuels, combustion and exhaust emissions of the world scientific literature through a bibliometric analysis. To accomplish this, we perform an analysis of publications, journals, institutions, source type, and document type, number of citations and countries in relation to publication year. An analysis of keywords of the works published is also performed.

2. Methods

Elsevier's Scopus database covers a significant part of the world scientific production. It represents the most influential and highest quality journals from a broad variety of disciplines and was selected for its vast abstract and citation collection. The following keywords were used: "fuel", "combustion", "diesel", "gasoline" and ("exhaust gas" OR "exhaust emission"). These words are selected to be in the titles, abstracts, and keywords of the published articles.

Trade Publications were excluded from this research because we are interested only in academic articles (the percentage of Trade Publications is 6%, 3%, 9%, 13% and 3% in the case of the keywords Fuel, Combustion, Diesel, Gasoline and "Exhaust gas or Exhaust emission", respectively. Moreover, as the great majority of scientific articles are published in English (more than 85-89% of the works using the above keywords), only the documents published in English were taken into account. Finally, the articles published in 2018 are excluded, as their number is on a continuing increase.

The documents were analyzed according to characteristics of publications such as Year, Subject Area, Document Type, Source Title, Affiliation, Country/Territory, and Source Type. Finally, the trends of scientific research are revealed through the keywords that were used by authors and by Scopus in all these publications.

In order to verify that a similar work is not performed recently, the search: (fuel OR diesel OR combustion OR gasoline OR ("exhaust gas" OR "exhaust emission")) AND bibliometrics is used.

The impact factors (IFs) were obtained from 2017 latest IF Journal List; Thomson Reuters (based on 2016 journal Citation Reports)

The total publications and citations per country were obtained by SCImago Journal & Country Rank. SCImago Journal & Country Rank is a portal that includes the journals and country scientific indicators developed from the information contained in the Scopus database.

3. Results – Discussion

3.1. Similar works

The search: (fuel OR diesel OR combustion OR gasoline OR ("exhaust gas" OR "exhaust emission")) AND bibliometrics) resulted in 34 articles. Six of them[30-35] analyzed the trends of fuel cells technologies. Other two articles are focused on bio-fuels[36-37]. The other 26 are not in the field of bibliometric analysis of the fuels/combustion pollution scheme. These results indicate that our research in not performed before and is an original one.

3.2. Total number of documents and analysis of publications per year

The first paper published (and covered by Scopus) dealing with "Fuel" is quite outdated; it is published in 1826. The first works corresponding to the keywords Combustion, Diesel, Gasoline, and "Exhaust gas" OR "Exhaust emission" are also very old (more than 100 years ago): 1837, 1898, 1897, and 1918.

The keyword Fuel gives in total 599,886 articles, Combustion gives 277,896, Diesel 120,513, Gasoline 59,980 and ("Exhaust gas" OR "Exhaust emission") 55,245. The number of articles of the keyword Fuel is more than 3 times more than the sum Diesel + Gasoline, because this keyword also covers other fuels, such as coal, kerosene, etc. and also other fields, such as extraction, transport, refining, etc., which are generally out of the scope of fuels combustion. The high number of Combustion articles (almost half of that of Fuels) is due to the study of theoretical aspects of combustion or the combustion on burners, etc. Diesel articles are almost the double in number than those dealing with Gasoline, due to the higher complexity of Diesel engines and to their higher number of applications (heavy-duty vehicles, marine engines, railway locomotives, etc.) comparing to gasoline ones.

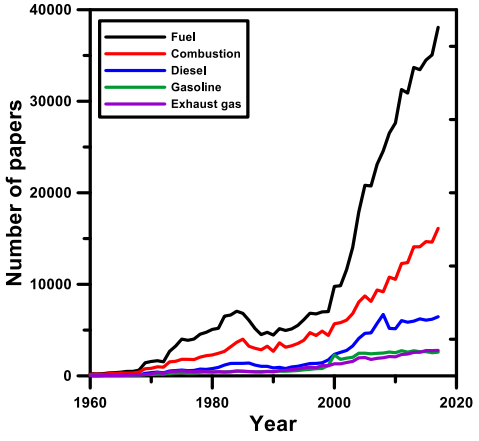

Figure 1. Number of documents published per year.

In order to have a comprehensive overview of the research production on "Fuel", "Combustion", "Diesel", "Gasoline" and ("Exhaust gas" OR "Exhaust emission"), the number of

documents published of each year is analyzed (Figure. 1). The analysis starts from 1960 due to the very low number of documents before this year.

Figure 1 shows that the first increase is observed in the beginning of 70's and that trend is maintained until about 1985 for all five keywords. After that date, a decrease is observed for 5-6 years, and a new increase occurs until the end of the 20th century. The slope of this increase becomes significantly higher after year 2000 for all five keywords. However, the Gasoline works show a constant publication rate five years later, while the publications about Diesel shows a sharp decrease in 2009-2010, to take up slowly after 2011. At the same time, the publication rate of the other three keywords constantly increases.

Several explications can be formulated for these trends. First of all, global scientific production shows a general exponentially increase (RederOlesen Larsen, 2010), and that increase is also applied in the case of the keywords used here. The two oil crises in the 70's resulted to an increase of oil prices (eia 2016) and thus to an increased the scientific interest about fuels and their better utilization; this is the reason for the initial increase observed in the number of publications until 1985. The 80's oil glut resulted in a decrease of oil production from 1980 to the mid-eighties. This decrease in oil production decreased the scientific interest and, thus, the number of publications decreased with a slight delay. The increase of oil production after the mid-eighties has an immediate increase of the global scientific production. This increase is even higher after year 2000 due to the increase of oil prices observed after this year. Moreover, the strict regulations concerning exhaust emissions and the pressures to increase energy efficient are complementary factors for the increase of scientific production observed after year 2000. It must be noticed that the constant rate of publications about Gasoline after 2005 indicated that this scientific filed reached a research saturation.

3.3. Document and source type

Of the total number of publications recorded to Scopus from 1826 to 2017 in our search, 15 document types are identified. Table 1 shows the number of documents per document type of each keyword and document type.

Table 1 shows that "article" is the dominant document type in all five keywords used here (56.8% to 65.6% of the total publications), followed by "conference paper" (25.5%-33.1%), "review" (2.0-3.5%), "note" (0.5-4.3%), and "book chapter" (0.3-1.3%). Several other document types are reported, but they are minor.

As a consequence of the previous results, more than the two thirds of the documents are published in journals (Fuels: 398,408 papers, 66.4%, Combustion: 198,892, 71.6%, Diesel: 81,512, 67.6% Gasoline: 42,157, 70.3%, Exhaust emissions OR Exhaust gas: 44,710, 81.0%), following by conference proceedings (Fuels: 135,992 papers, 22.7%%, Combustion: 60,703, 21.8%, Diesel: 22,666, 18.8%, Gasoline: 7,857, 13.1%, Exhaust emissions OR Exhaust gas: 7,318, 13.3%), while the other media are minor.

Table 1. Total number of documents per document type for each keyword and corresponding percentage

Document type	Fuel	%	Diesel	%	Combustion	%	Gasoline	%	Exhaust gas	%
Article	362965	60,51	68403	56,76	182405	65,64	35220	58,72	36171	65,51
Conference Paper	174311	29,06	39974	33,17	80220	28,87	15289	25,49	14941	27,06
Review	21176	3,53	3395	2,82	5806	2,09	1671	2,79	1802	3,26
Note	10961	1,83	3017	2,50	1477	0,53	2495	4,16	735	1,33
Book Chapter	8112	1,35	744	0,62	2060	0,74	542	0,90	207	0,37
Business Article	6420	1,07	2120	1,76	179	0,06	3415	5,69	43	0,08
Conference Review	3842	0,64	916	0,76	2101	0,76	254	0,42	225	0,41
Short Survey	3517	0,59	917	0,76	642	0,23	334	0,56	295	0,53
Article in Press	1973	0,33	348	0,29	789	0,28	103	0,17	120	0,22
Book	1888	0,31	114	0,09	486	0,17	87	0,15	5	0,01
Letter	1419	0,24	193	0,16	502	0,18	300	0,50	345	0,62
Editorial	1252	0,21	118	0,10	405	0,15	118	0,20	256	0,46
Report	888	0,15	53	0,04	322	0,12	14	0,02	38	0,07
Erratum	638	0,11	96	0,08	216	0,08	43	0,07	1	0,00
Abstract Report	468	0,08	96	0,08	272	0,10	94	0,16	30	0,05

3.4. Analysis per field

The six more frequent subject areas based on the number of total publications are shown in figure 2 for each of the five keywords investigated in this paper. Generally, there is an increase in publications with time in most of the subject areas of most of the keywords used here. The four subject areas: Engineering, Energy, Environmental Sciences, Chemical Engineering and Chemistry are found in all six keywords. Physics and Astronomy is found in 3 keywords, while Earth and Planetary Sciences and Medicine are found in one keyword each.

Engineering is generally the area with the highest number of papers and the area with the highest increase in number of papers with time. Energy is usually the second or third subject area in all keywords, while Chemical Engineering and Environmental Sciences follow. The area of Environmental Sciences is found on the first/second position with the area Engineering in the case of Exhaust emissions OR Exhaust gas, while the area of Medicine is also found within the first positions in the case of this keyword, as several works study the effect of exhaust pollutants on health.

Figure 2 shows that the number of publications increases with time with most of the keywords used here and most of the scientific areas. Figure 3 shows the relative contribution of each field, namely the evolution of the percentage of each field. It must be noticed that the sum of these percentages can be higher than 100%, as some articles can be classified into more than one fields. Figure 3 shows that the relative contribution of Engineering had an increase until 1970-1980; a constant contribution is observed in later years and a significant decrease after 1990. The other keywords show a constant contribution or increase until 1980, while an increase is observed in most of the cases after that date. The increasing trend of Energy and Environmental Science are generally the most remarkable during last years.

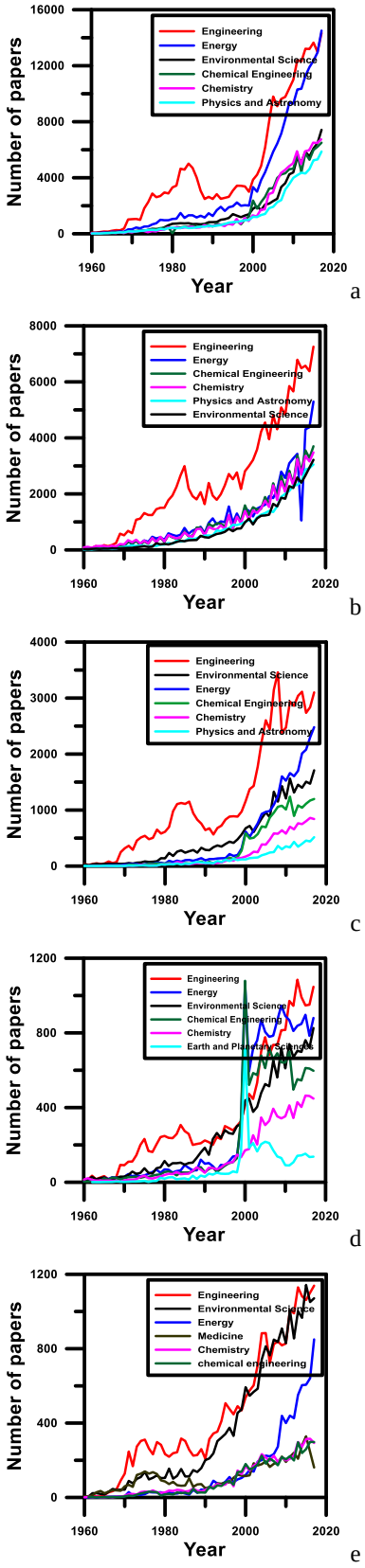

Figure 2. Evolution of the annual number of publications for top 6 productive subject Areas (1960-2017) (a) Fuel, (b) Combustion, (c) Diesel (d) Gasoline, (e) Exhaust

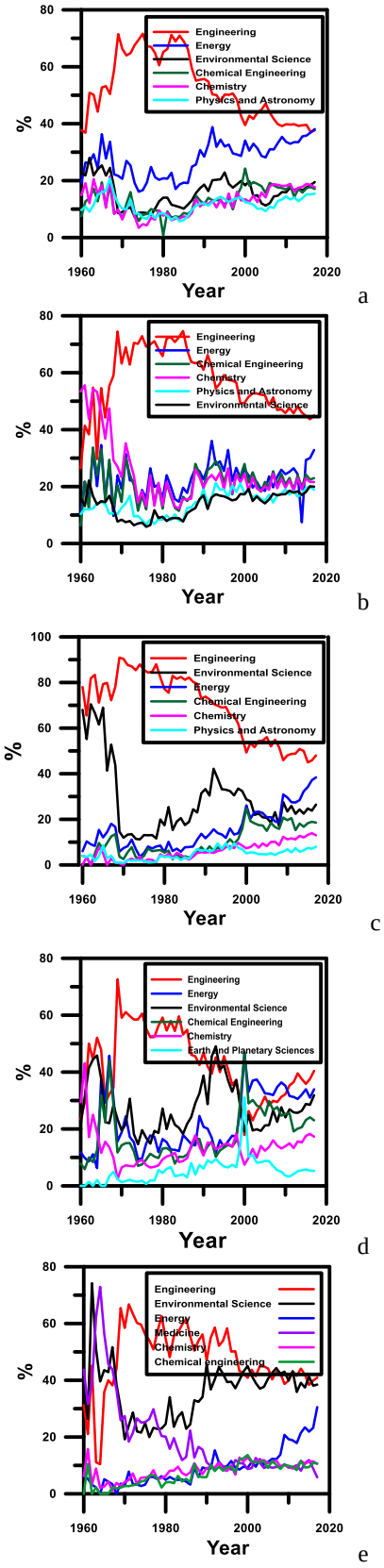

Figure 3. Evolution of the percentage of the top six most productive subject areas (1960-2017) (a) Fuel, (b) Combustion, (c)Diesel, (d) Gasoline, (e) Exhaust gas OR Exhaust

3.5. Analysis of the major sources of publication and citation

There is a high number of journals published the works corresponding to our research; however, as Scopus has an export limit of only 160 terms, our analysis is focused only in the first 160 journals. For the five keywords used here (Fuel, Combustion, Diesel, Gasoline, Exhaust Emissions OR Exhaust Gas), the first 160 journals cover respectively 39%, 45%, 50%, 55% and 54% of the total number of papers published. Figure 4 shows for each keyword, the cumulative percentage of articles covered by these journals as a function of the number of journals that publish them, in decreasing order of journals, according to the number of articles they have published. It is of interest that the first 80 journals (the half of Scopus output) have published only the 30% of the articles of "Fuel", the 35% of "Combustion", the 40% of "Diesel", the 45% of "Gasoline" and the 45% of "Exhaust gas". We can conclude that although the journals with highest productivity cover a significant part of the total articles published, a high predominance of specific journals in the fields of fuels and combustion is not observed.

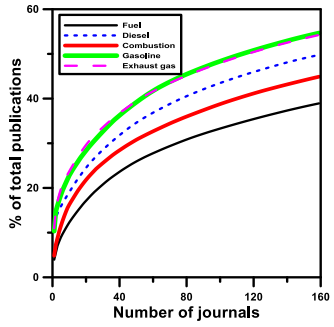

Figure 4. Cumulative percentage of papers published as a function of the number of journals have published them for each keyword

The 10 most productive journals of each keyword are shown in Table 2. The 10 first journals comprise 12%, 16%, 19%, 22%, and 24% of the total publications in keywords Fuel, Combustion, Diesel, Gasoline, and Exhaust emission OR Exhaust gas, respectively. The first source in the journal list is SAE Technical Papersfor all five keywords (3.9%, 4.8%, 11.9% 10.3% and 11% for the five keywords respectively).

The Impact Factor of a journal is a metric measuring the average number of citations received in a particular year by papers published in the journal during the two preceding years. A linear relationship is seen between the ranking of journals or the number of papers published in each journal and its' Impact Factor. No such correlation exists, as the coefficient of linear relationship between the ranking number of documents and impact factor is 0.10-0.73 and the number of papers and Impact Factor 0.14-0.58.

Because of the quite low number of papers (comparing to the total ones) and relative contribution (percentage) of each journal, the evolution of these parameters have significant variations in time and do not show clear trends. For this reason, they are not shown here.

Table 2. Ranking of the 10 most productive journals in terms of publications for each keyword used here

	Fuel			Combustion			Diesel			Gasoline			Exhaust gas or Exhaust emission		
Ranking	Journal name	Number	IF	Journal name	Number	IF	Journal name	Number	IF	Journal name	Number	IF	Journal name	Number	IF
1	SAE Technical Papers	23687		SAE Technical Papers	13430		SAE Technical Papers	14457		SAE Technical Papers	6195		SAE Technical Papers	6069	
2	International Journal Of Hydrogen Energy	9446	3.582	Combustion And Flame	6933	3.663	Fuel	1697	4.601	Oil And Gas Journal	2685	0.048	Atmospheric Environment	2189	3.629
3	Journal Of Power Sources	9300	6.395	Proceedings Of The ASME Turbo Expo	4106		NeiranjiGongcheng Chinese Internal Combustion Engine Engineering	1106		Hydrocarbon Processing	773		Environmental Science And Technology	1143	1.915
4	Ecs Transactions	5811	-	Fuel	4036	4.601	Energy And Fuels	965	3.091	Environmental Science And Technology	736	1.915	Science Of The Total Environment	825	4.9
5	Fuel	5386	4.601	Symposium International On Combustion	3381		NeiranjiXuebao Transactions Of CSICE Chinese Society For Internal Combustion Engines	904		Fuel	669	4.601	Journal Of The Air And Waste Management Association	672	1.57
6	Proceedings Of The ASME Turbo Expo	4482		Proceedings Of The Combustion Institute	3200	3.214	Advanced Materials Research	809		Petroleum Processing And Petrochemicals	616		Proceedings Of The ASME Turbo Expo	499	
7	Energy And Fuels	4030	3.091	Combustion Science And Technology	2897	1.241	Oil And Gas Journal	804	0.048	Atmospheric Environment	520	3.629	Fuel	480	4.601
8	Journal Of Nuclear Materials	3968	2.048	Energy And Fuels	2708	3.091	Atmospheric Environment	760	3.629	Hydrocarbon Engineering	499		Environmental Health Perspectives	445	9.776
9	Energy	3817	4.52	Combustion Explosion And Shock Waves	2498	0.889	Energy	724	4.52	Chemistry And Technology Of Fuels And Oils	490	0.317	Energy	401	4.52
10	Oil and gas journal	3691	0.048	American Society Of Mechanical	1958		Energy Conversion And Management	724	5.589	Federal Register	484		Energy conversion and management	374	5.589

3.6. Analysis of countries

The 10 most productive countries for each keyword are shown in Table 3. The most productive country in all five keywords is the USA, followed by China. Japan is third in the case of 4 keywords and fourth in one case. The other countries are Canada, Western European countries (UK, Germany, France and Italy), India, South Korea and, in one case each, Brazil and Russian Federation. It is worthy to mention that 12 countries always occupy the 10 first places.

Table 4 shows, for the 12 countries of Table 3, the total number of documents published in the field of Energy, then the total number of citations and their H-index. These data come from the SCImago Journal & Country Rank.

For each of the 5 keywords examined here, a correlation between the data of Table 3 (ranking of each country and number of documents published) and the data of Table 4 is performed. The results show that the ranking of each country in the Energy field is well correlated with the ranking in each of the keywords used here (r=0.82-0.93); and the number of total documents in our searches with the total documents in the field of Energy (r=0.82-0.96) indicating that the publications of each keyword follows the general trend of Energy publications.

Table 3. Ranking of the 10most productive countries in terms of publications for each keyword used

Ranking	Fuel		Combustion		Diesel		Gasoline		Exhaust gas or exhaust emission	
	Country	Number	Country	Number	Country	Number	Country	Number	Country	Number
1	USA	144799	USA	66444	USA	22267	USA	15211	USA	12511
2	China	65568	China	42317	China	16616	China	7870	China	5530
3	Japan	35952	Japan	15235	India	6577	Japan	2662	Japan	4513
4	United Kingdom	29396	Germany	15075	Japan	5873	United Kingdom	2259	Germany	3969
5	Germany	28883	United Kingdom	13705	United Kingdom	5099	Germany	2090	United Kingdom	3169
6	India	22812	India	10711	Germany	4707	Canada	1540	India	2527
7	Canada	18894	Russian Federation	8606	Italy	3044	India	1375	Italy	2050
8	South Korea	17358	France	8565	France	3649	Italy	1246	France	1530
9	France	17109	Italy	8451	Canada	2631	France	1221	Canada	1399
10	Italy	15127	Canada	6711	South Korea	2504	Brazil	1204	South Korea	1361

Table 4. Contribution of the top productive countries of Table 2 (data from SCImago 1996-2016 in the field of Energy)

Country	Documents ranking	Total Documents	Total citations	H-Index
China	1	232980	1714855	228
United States	2	218345	2600944	344
Japan	3	69832	715149	205
Germany	4	52451	613923	202
UK	5	49307	652590	223
India	6	44427	467983	188
France	7	36611	466461	179
Canada	8	35758	527122	217
Russian Federation	9	35384	112945	87
South Korea	10	31385	368612	153
Italy	11	30631	365270	158
Brazil	12	17934	167224	119

As the total number of publications increases with time, the number of publication of each country also increases (in general). For this reason, only the relative contribution of each country is shown here. Figure 5 displays the evolution of the relative contribution of the six most productive countries. The USA have a general predominant role in all five keywords. However, the relative contribution of USA shows a very sharp decrease from 1970 to 1990 to increase later but never to the level before 1970. After 1990, the relative contribution of USA follows a general decreased trend. The same decreased trend occurs in the case of the other Western Countries and Japan. China, from a very low contribution until 1990, shows a remarkable increase after that year, to be the first country today. The same trend is observed in the case of India but with

lower number of publications.

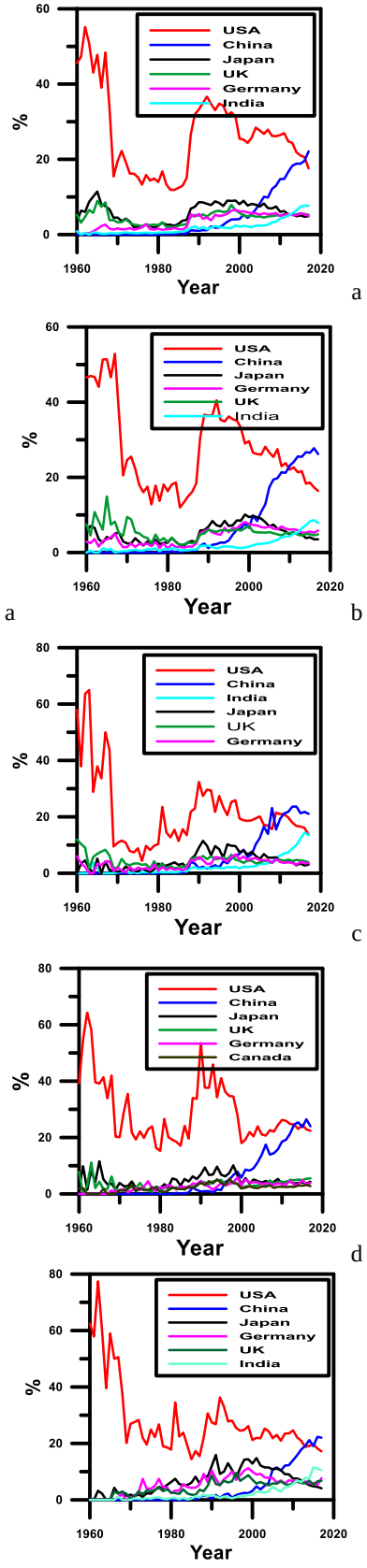

Figure 5. Evolution of the percentage of the top six most productive countries (1960-2017) (a) Fuel, (b) Combustion, (c)Diesel, (d) Gasoline, (e) Exhaust gas OR Exhaust Emission

3.7. Analysis of institutions

The 10 most productive institutions for each of the five keywords studied in this research are shown in Table 5.

It is remarkable that from the 50 places, the 23d are occupied by Chinese institutions, the 21st by USA, the second from France and Japan and the first from Russian Federation and Spain. Moreover, four Chinese institutions appear in the first five places (Chinese Academy of Sciences (5 times), Tsinghua University (5), Ministry of Education China (4), Tianjin University (4)) following by one from USA (General Motors (3 times)).

Because of the quite low number of papers comparing to the total ones and relative contribution (percentage) of each institution, the evolution of these parameters have significant variations in time and do not show clear trends. For this reason, they are not shown here.

3.8. Analysis of the keywords

Keyword investigation helps researchers choose keywords related to new publications and contributes to access to them from scientific database with the correct term for the research theme (Blank et al., 2016). Statistical analysis of keywords can be used to identify directions in science and technology and bibliometric analysis can be used for that purpose.

When searching to Scopus for a specific topic, the extracted keywords are a combination of author keywords (assigned to the documents by the authors) and indexed keywords (controlled vocabulary terms and indexing vocabulary terms from subject-specific databases assigned to the documents by Scopus). For each of the five searches, the total number given by authors and by Scopus are 160 keywords. These 160 keywords give 1,544,120 total frequencies in the case of Fuel, 906,997 total frequencies in the case of Combustion, 430,085 total frequencies in the case of Diesel, 230,313 in the case of Gasoline and 340,942 in the case of Exhaust Gas or Exhaust Emission.

For further analysis, the first 160 keywords (extracted by Scopus with the highest frequency) are categorized to some general categories, according to their content. These keywords, their frequency and their category are shown in appendix.

Figure 6 shows the frequencies of these general categories, while figure 7 shows the number of keywords within each of these categories.

Table 5. Ranking of 10 most productive institutions in terms of publications for each keyword used here

Ranking	Fuel		Combustion		Diesel		Gasoline		Exhaust gas	
1	Chinese Academy of Sciences	7265	Chinese Academy of Sciences	4116	Tianjin University	1229	Tianjin University	677	United States Environmental Protection Agency	653
2	Tsinghua University	4771	Tsinghua University	2721	Tsinghua University	936	Sinopec	641	Ford Motor Company	593
3	Ministry of Education China	4275	Russian Academy of Sciences	2569	University of Wisconsin Madison	866	Tsinghua University	572	Chinese Academy of Sciences	589
4	Japan Atomic Energy Agency	3565	Ministry of Education China	2554	Shanghai Jiao Tong University	789	Chinese Academy of Sciences	521	General Motors	480
5	Oak Ridge National Laboratory	3501	CNRS Centre National de la RechercheScientifique	1984	Beijing Institute of Technology	772	Research Institute of Petroleum Processing	506	Tianjin University	462
6	Argonne National Laboratory	3403	Huazhong University of Science and Technology	1756	General Motors	705	Ford Motor Company	505	Tsinghua University	392
7	CNRS Centre National de la RechercheScientifique	3251	Zhejiang University	1696	Jiangsu University	670	General Motors	461	National Institute for Environmental Studies of Japan	302
8	Pennsylvania State University	3099	Tianjin University	1600	Universitat Politècnica de València	649	United States Environmental Protection Agency	432	UC Berkeley	285
9	Massachusetts Institute of Technology	2999	Pennsylvania State University	1559	Chinese Academy of Sciences	642	Exxon Mobil Corporation	425	Ministry of Education China	284
10	UC Berkeley	2753	University of Science and Technology of China	1441	Ministry of Education China	639	Argonne National Laboratory	345	Shanghai Jiao Tong University	274

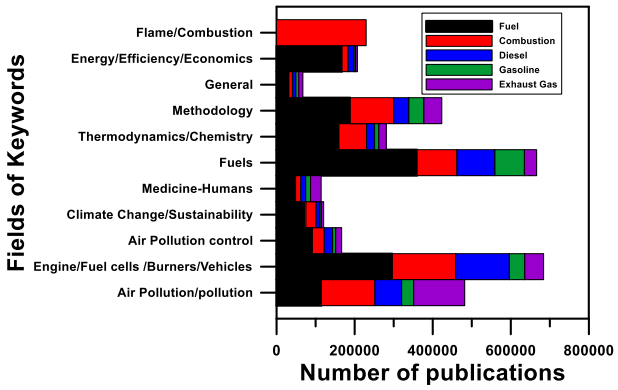

Figure 6. Number of publications in every category

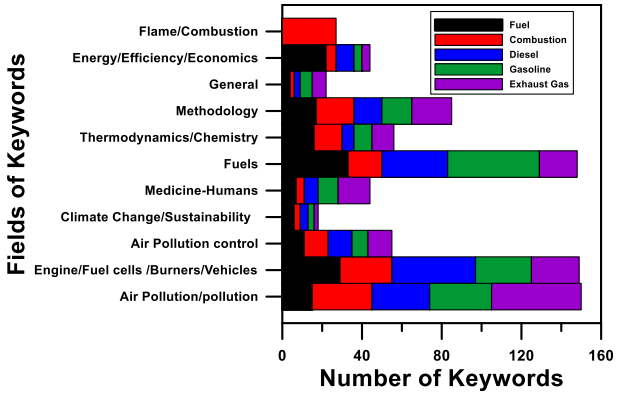

Figure 7. Number of keywords in every category

Figure 6 shows that in the case of keyword "Fuel" the most productive category is, as expected, the category "Fuel" followed by "Engine/Fuel cells/Burners/Vehicles". In the last category, the number of publications dealing with vehicles is very small, indicating that this category is not referred only to vehicles but also to other ways of energy production such as nuclear power or electricity. The same trend is indicated by the number of keywords (Figure 7). It is of interest that the two categories "Air pollution" and "Air pollution control" together have many publications and include 26 keywords covering the 16% of the total number of keywords after the first category which is "Fuels" with 30 keywords. As a result, there is a high interest in the environmental degradation which is contributed by fuels and also in the technological ways which could help in its protection.

In "Combustion" the most productive category is "Flame/Combustion". The other categories show almost the same number of publications, except from "General", "Climate Change/Sustainability" and "Medicine/Humans" which are minors.The same trend is indicated by the number of keywords.

In Diesel, the highest interest is focused on "Engine/Fuel cells/Burners/Vehicles" and "Fuels". In contrast to "Air pollution/Pollution", there is a smaller amount of papers in "Air pollution control". However, these two fields together include 44 keywords covering the 27% of the total number of keywords in contrast to the biggest field "Engine/Fuel cells/Burners/Vehicles" which includes 41 keywords covering a smaller amount. The highest scientific interest focuses on the "Engine" issues followed by environmental themes and their control.

In Gasoline, the most productive category is "Fuels". All the other categories have almost the same amount of papers, except the minors: "Climate Change/Sustainability", "General" and "Air Pollution Control". However, the field of "Air Pollution Control" shows a high number of keywords, and with "Air pollution/Pollution"include 38 keywords covering the 24% of the total number of keywords, indicating the interest of scientists in environment.

Finally, in 'Exhaust gas" the most productive category is "Air pollution/Pollution", with a significant number of papers is found in "Medicine".

Generally, in all five cases the environmental issues play an important role in the scientific interest. It is remarkable that in all cases the number of keywords for these environmental categories is high. In 'Fuel" (26 keywords, 16% of the total), in "combustion" (39 keywords, 25%), in 'diesel" (44, 27%), in "gasoline" (38 keywords, 29%)and in "exhaust gas" (56 keywords, 35%). These results show that the fields of "air pollution" and "air pollution control" are highly productive and this could merit further investigation.

4. Conclusions

Based on the database of Scopus, this paper studied the evolution and characteristics of the scientific production on fuels, combustion and exhaust emissions fromusing bibliometric techniques. In order to cover this field we used five keywords "fuel", "combustion", "diesel", "gasoline" and ("exhaust gas" OR "exhaust emission"). A notable increase in publication of papers is observed in the beginning of 70's until about 1985 for all five keywords, probably because there were two oil crises in the 70's which resulted to an increase of oil prices and thus to an increase in the scientific interest about fuels and their better utilization. A decrease for some years is observed after that date apparently related to the 80's oil glut that drives the scientist interest away from this field. The increase of oil production after the mid-eighties has an immediate increase of the global scientific production. This increase is even higher after year 2000 due to the increase of oil prices, except, very recently in the case of gasoline and diesel, indicating the saturation of these fields. Moreover, the strict regulations concerning the exhaust gases and the need for more efficient energy after 2000, rises the scientific interest for these fields.

Article is the most commonly used document type followed by conference paper and reviews in all five cases. Engineering is the most productive subject area in all five cases followed by Energy in "fuel", "combustion", and "gasoline" and by Environmental Science in "diesel" and ("exhaust gas" OR "exhaust emission"). Investigating the evolution of the percentage of each subject area for all cases, we concluded that

the relative contribution of Engineering had an increase until 1970-1980 then a constant contribution and significant decrease after 1990. The other subject areas show a constant contribution or increase until 1980, while an increase is observed in most of the cases after that date. It is of interest that the subjects Energy and Environmental Science show an increasing trend during the last years. SAE Technical Papers has the highest number of works in all categories followed by International Journal Of Hydrogen Energy, Combustion And Flame, Fuel, Oil and Gas Journal and Atmospheric Environment in "fuel", "combustion", "diesel", "gasoline" and ("exhaust gas" OR "exhaust emission"), respectively. Analyzing that field, we concluded that the first 80 journals (the half of Scopus output) have published only the 30% of the articles of "Fuel", the 35% of "Combustion", the 40% of "Diesel", the 45% of "Gasoline" and the 45% of "Exhaust gas". As a result, although the journals with highest productivity cover a significant part of the total articles published, this trend is not observed in the fields of "fuels" and "combustion".Moreover there is no correlation between ranking number of documents and impact factor.

The most productive country is USA followed by China in all five cases. The third position covers the Japan in all cases except for "diesel" that India is in the third position. However it is of interest that USA publications is in downward or constant trend after 2000 until 2017 while trend in the case of China is upward. Finally, comparing the ranking of each country in the Energy field with the ranking in each of the keywords used in our study, they show a good correlation indicating that the publications of each keyword follows the general trend of Energy publications.

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