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Development of Carbon-based Nanomaterials Indicators Using the Analytical Tools and Data Provided by the Web of Science Database

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The recent rise of nanotechnology and nanomaterial research is marked by the huge amount of publications indexed in electronic databases, which can be evaluated using bibliometric indicators in order to help researchers find hidden trends, gain novel insights and support new scientific developments. Although in-depth analyses require specialized software and advanced methodologies, some initial indicators can be developed using the analytical tools available in databases and provide useful information about a specific subject or research field. This paper aims to explore the Web of Science's analytical tool for analyzing the scientific output regarding carbon-based nanomaterials. The results provide several key findings, including research trends and publications in carbon nanotubes, fullerene and graphene, as well as revealing the main global players and journals from 2001 to 2010. Despite the usefulness of the analytical tool, a number of limitations hindered the development of important indicators, such as those involving citation and collaboration.

Keywords: *bibliometrics, scientometrics, carbon nanotubes, fullerenes, graphene*

1. Introduction

Over the last few decades, there has been increasing interest in nanotechnology and current advances have been quite striking and evident from publication and patent data due to worldwide efforts in research and investments from funding programs[1-5]. While in 2005 the global public spending in the field was estimated at US$ 4.5 billion[1], in 2011 the total global funding reached a round figure of US$ 10 billion[5]. The USA, China, Japan, Germany, South Korea, France, Russia, the UK, India and Italy have been the most prolific countries in the nanotechnology field. For instance, the US National Nanotechnology Initiative has invested cumulatively totaling US$ 18 billion (including the 2013 request) since its inception in 2001 and the budget for 2011 was US$ 1.8 billion[6]. The Chinese government invested US$ 893 million during 2005-2007 period[2] in its nanotechnology program and in 2011 its budget achieved near US$ 2.3 billion[5].

An important aspect of nanotechnology is the nano-scale structures of materials, which involves typical dimensions between 0.1 and 100 nanometers (nm)[7], equivalent to 100,000 times smaller than the size of a human hair. At this scale, nanomaterial can exhibit particular behaviors which can be exploited in the development of new technologies and products for society[2,4,8-12]. Therefore, nanomaterials have been received considerable attention from nanotechnology governmental programs[5]. Among the promising nanomaterials, special attention has been paid to carbon-based nanomaterials (carbon nanotubes, fullerenes and graphene) due to their unique mechanical, physical and chemical properties and high potential of application mainly in the field of electronics, optics and engineered materials[8-12].

Recently, there has been wide interest in using bibliometric indicators to measure productivity in science and technology (S&T), communication and performance evaluation in order to support planning and research developments[4,13-15]. Bibliometrics aims to measure registered scientific and technological communication using mathematical and statistical counting of articles, patent documents, citation, words and terms to find hidden trends and patterns, and to gain insights into a subject characterized by different levels of stratification[12].

Due to its capability to analyze large volumes of data and information, bibliometrics has been used to evaluate quantitatively the research performance of complex, emergent and highly productive areas, such as nanotechnology. For instance, Kostoff, Koytcheff and Lau[9] exploited the nanotechnology research literature from 1991 to 2005 using data from the Science Citation Index and Social Science Citation Index databases (Web of Science). They separated the publications into clusters according to nanotechnology taxonomies and mapped the prolific authors, key journals, institutions and countries, and the most cited authors, journals and documents using bibliometrics[9]. Beaudry and Allaoui[10] measured the impact of public grants, private contracts and collaboration of Canadian nanotechnology academics by crossing data names from the scientific publications indexed in Scopus, granted patent from USPTO and contracts registered with the University Research Information System. Chang, Wu and Leu[11] used statistical and citation analysis in patent documents to

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monitor technological trends in carbon nanotubes field emission display and they revealed different aspects of patenting activities and the role of the emitter material to improve the efficacy in CNT-FED technology. Lately, the rapid increase in scientific research and technological development in graphene has been verified using absolute number, collaboration, total of citation and co-word analysis of papers and patents clusters[12].

A huge quantity of information has been made available due to recent advances in information technologies and accessibility to electronic databases. Consequently, general analyzing procedures and methods have become complex, requiring specialized tools and software[16,17], which are in most cases commercial and not easily accessible. Nevertheless, technological advances have also taken place in databases that started to provide analytical features for users to diagnose quantitatively the results of their searches[18,19]. An insightful database analytical feature is the "Analyze Results" from the Web of Science[18] which is able to count the publication data from worldwide scientific production indexed and helps to compile useful indicators. Some studies have employed the Web of Science to identify leading authors, journals, institutions, and countries[20-22]. Osorio and Otieno[22], for instance, evaluated the productivity of Brazilian engineers from 2000 to 2006 and found that Materials Science was the most active technology field. However, none of them provided a detailed procedure of how to compile those indicators using the database feature.

Despite the contribution of bibliometric indicators to develop knowledge in carbon-based nanomaterials, most of the bibliometric work performed currently has used highly complex computational tools and sophisticated methods to analyze large volumes of data, and the specialized features are usually proprietary and not easily accessible by researchers and engineers. The database analytical tool can be applied to evaluate comparatively the scientific (outputs) publication related to carbon nanotubes, fullerenes and graphene. In order to fill in those gaps, the purpose of this investigation is to explore the Web of Science[18] analytical tool to provide useful scientific publication indicators on carbon-based nanomaterials and to help non-specialists in bibliometric analyses gain initial insights into their scientific area or subject of interest. The remainder of this paper is divided into three sections. Section 2 describes the experimental procedures, while section 3 presents the results and discusses the limitations of the method used. Finally, section 4 outlines the conclusions.

2. Experimental Procedures

2.1. *Data source, search expression and indicators developed*

Scientific indicators for carbon nanotubes, fullerenes and graphene were developed using the bibliographic data available from Science Citation Index Expanded. The sample investigated comprised 65,307 scientific publications from 2001 to 2010 recovered by using the search strategy for carbon nanotubes, fullerenes and graphene presented in Table 1. In the case of nanotechnology, previous studies have discussed the challenge of retrieving and identifying nanotechnology-related publications[3,4,23]. However, Huang et al.[23] performed a comparative analysis of search strategies used in the literature, including lexical queries, evolutionary lexical queries, citation analysis and the use of core journal sets. They concluded these strategies produced very similar rankings because they share a core set of keywords, except for the journal set, which did not provide a robust delineation of the area. Therefore, we used the modular search strategy suggested by Porter et al.[3], since it has the advantage of including nano-related terms revised by experts and specialized journals from the nanotechnology area and a step of excluding non-related terms that have the radical "nano".

All the searches were conducted in the Topic field, which retrieve terms from the title, abstract and keywords, except in the case of nanotechnology strategy, which required adding the Publication Name field of search[3]. All searches were also limited to Articles, Letters, Notes and Reviews, based on international procedures for developing indicators[13,15].

The evolution and main countries, institutions and journals were mapped for each carbon-based nanomaterial. The evolution data of nanotechnology publication were accurately included for comparative purposes. In addition, the following was analysed: the quantity of records in common among carbon nanotubes, fullerenes and graphene and between these selected nanomaterials and nanotechnology using the Boolean operator "AND" to combine the search expressions shown in Table 1. Graphs and tables were developed using Microsoft Office Excel (version 2007) from the results of the Web of Science analytical tool. All searches and analysis were carried out between September 17th and 18th, 2012.

2.2. *Procedure for developing indicators using the Web of Science analytical tool*

The development of the indicators was rigorously conducted as will now be described. After searching, the results were analyzed with the "Analyze Results" tool from the Web of Science[18], the interface of which is highlighted in Figure 1. The "Analyze Results" tool from the Web of Science has an interface that enables users to develop rankings from information of 16 specific fields of an indexed record. For the purpose of this investigation, five of them can be highlighted: Publication Year, Country and Territories, Source Titles, Organization and Organization-Enhanced.

Table 1. Search expressions and total number of publications recovered from 2001 to 2010 for carbon nanotubes, fullerenes, graphene and the nanotechnology field.

Topic	Search Expression	Number of Publications
Carbon nanotubes	"carbon nanotub*"	46,906
Fullerenes	fulleren*	15,251
Graphene	graphene*	8,378
Nanotechnology	Recommended by Porter et al.[3]	616,321

* is the truncation operator; Source: Science Citation Index Expanded/ Web of Science.

The field option Organization-Enhanced was used instead of field Organization because it includes the name variants from the Preferred Organization Index[24] for the regular organization name.

Another function is the Set Display Option, which shows the top 10, 25, 50, 100, 250, or 500 results and can select a minimum record count to appear in the ranking, as presented in Figure 2. Finally, it is possible to order the results using the function Sort By, which ranks from high to low values according to the number of records in which each value (minimum record count) appears (*Record Count* option) or sorts the list in ascending alphabetical (A-Z) or numerical (0-9) order (*Selected Field* option). In addition, after selecting a specific field and configuring the set display, the analytical tool supplies the elements outside of the display and the number of records that do not contain data in the field being analyzed.

To determine the temporal data of publication per country and institution, in order to calculate the average percentage growth from 2001 to 2010, the feature "View Records" was used due to the fact that it is not possible to cross data in a straightforward way from different fields using the analytic tool (for instance, it is not possible to cross directly the data from countries with the publication year). Therefore, we used a three-step procedure for indirect data crossing, as illustrated in Figure 3a-c, which exemplifies the country-publication year. Prior to that, the top ten countries were ranked (A) to show the top 500 with a minimum record of one (B) and sorting by record count (C), and then the option *Analyze* was selected (D). The next step was to choose a specific country (E) and its publication was restricted by clicking in the option *View Record* (F), as can be seen in Figure 3a. Afterwards, we carried out a new analysis, selecting the "Analyze Results" tool again (G, Figure 3b). Finally, a new rank was created according to the publication year (H), setting the data to the top 500 results with a minimum record count of one (I) and sorted by numerical order choosing the option *Selected Field* (J). The results of these steps were related to the annual publication of the selected country. This procedure was repeated analogously for other top countries and for the top ten institutions. Furthermore, the outcome values from the analytical tool can be exported by clicking in *Select Analysis Data to File* (K), after choosing the options *Data rows displayed in table* or *All data rows*. A plain text file will be downloaded with all the values analyzed by the feature.

2.3. *Calculations performed*

The annual percentage growth (G_i) was calculated using Equation 1 below, where N_i is the number of publications

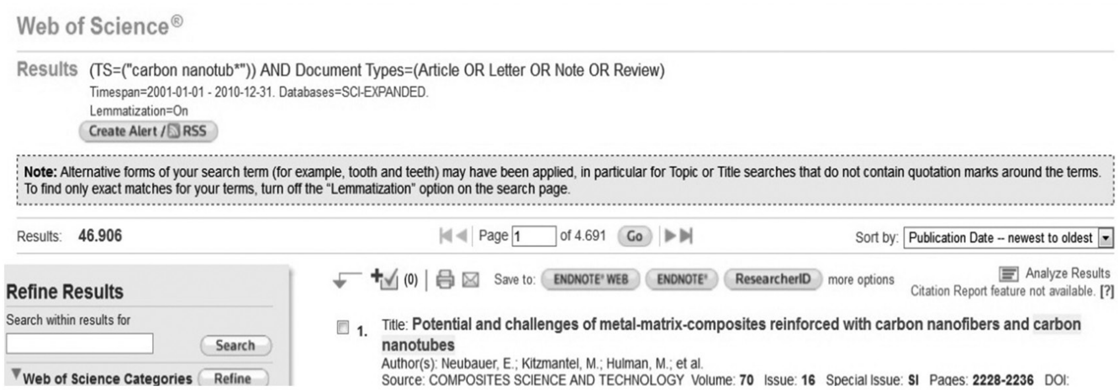

Figure 1. Illustration of the Web of Science analytical tool accessible from the "Analyze Results" in the search results screen. Source: Web of Science.

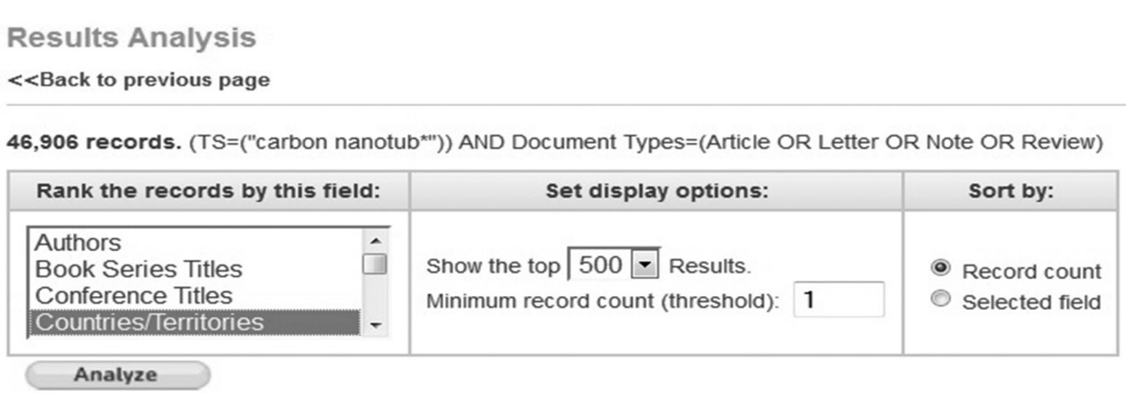

Figure 2. Interface of the Web of Science analytical tool. Source: Web of Science.

in the year "i" and N_{i-1} is the number of publications in the year "i-1". The average annual growth was obtained from the simple mean of annual rates for the period of 2001 to 2010.

$$G_i = \frac{(N_i - N_{i-1}) \times 100}{N_{i-1}} \quad (1)$$

The contribution (Ci) was calculated using the Equation 2 below, where Ni is the number of publication of "i" and T is the total of publication of the "i" context. The "i" can be a subject, country, institution or journal. Furthermore, all calculations and graph representation were performed with the software Microsoft Office Excel (2007 version).

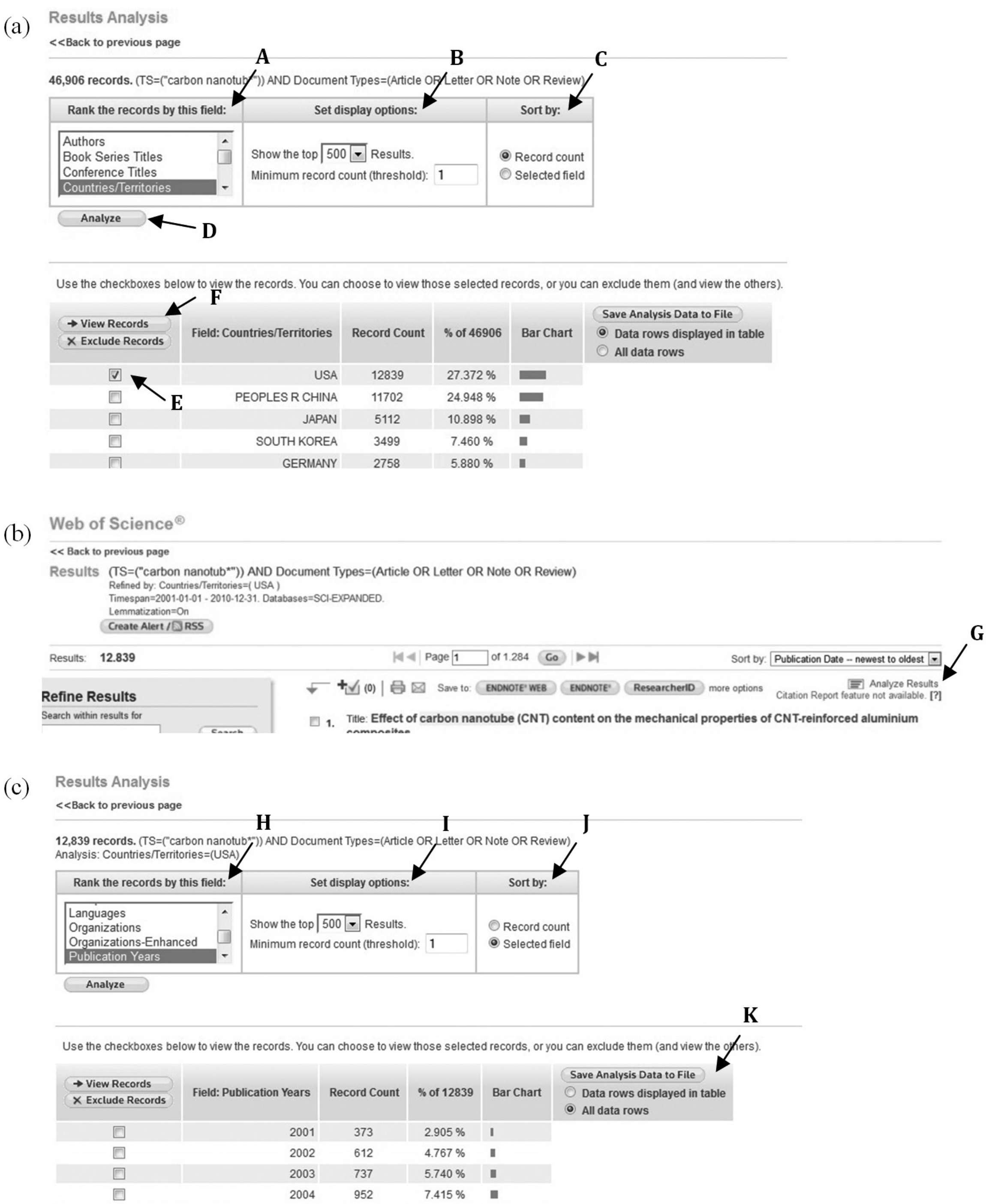

Figure 3. Procedure for indirect data crossing exemplified to obtain the annual publication data from the United States on carbon nanotubes. Source: Web of Science.

$$C_i = \frac{N_i}{T} \quad (2)$$

2.4. *Evaluation of the method proposed*

In order to evaluate the method of using the Web of Science analytical tool to develop scientific indicators and discuss its limitations and drawbacks, the following analysis was carried out. To assess the future capacity of replication of the indicators, new searches for each carbon-based nanomaterial was performed on April 6th, 2013 using the same search expressions and limits described below. The number of publication per year was obtained using the analytical tool and using bibliometric software (in this case, after downloading the complete bibliographic record datasets for each nanomaterial). The number of publication per year was compared from the results obtained on September 17th and 18th, 2012 and on April 6th, 2013. The bibliometric software used was *VantagePoint* (version 5.0).

The type of information available to be analyzed in the analytical tool was compared with a regular complete raw record imported from the Web of Science[25]. Another issue checked was the consistency of the institution's total number of publications, because they might have different denominations. In this case, the total publications of two main institutions (Tsinghua University and University of California) in carbon nanotubes was obtained from two fields of the analytical tool ("Organization" and "Organization-Enhanced") and from bibliometric software, in which there are features to clean and standardize institution names. Other limitations have been discussed elsewhere considering more sophisticated bibliometric analysis[14,15].

3. Results and Discussion

3.1. *Evolution of scientific production of carbon-based nanomaterials and nanotechnology*

The Web of Science historical search showed that carbon-based nanomaterials have accumulated 65,307 publications from 2001 to 2010, in which 62,460 publications were identified in the dataset recovered for nanotechnology, as can be seen in Figure 4a. Interestingly, the total number of publications on carbon-based nanomaterials publication represents 10.1% of the nanotechnology area, considering the total of 616,321 recovered for nanotechnology. However, a total number of 2,847 publications, which represents 4.6% of the total carbon-based nanomaterials publications, were not found by the nanotechnology search strategy due to the fact that the term used to retrieve graphene data was not used in the nanotechnology search expression. Arora et al.[26] have recently updated Porter's nanotechnology modular search strategy in order to attempt changes of emerging technology definitions over time and many new nano-related terms and journal names were included.

Comparisons among the total number of publications recovered by the three carbon-based nanomaterials search strategies are illustrated in Figure 4b, in which 46,906 publications (71.8%) referred to carbon nanotubes, 15,251 (23.4%) to fullerenes and 8,378 (1.,8%) to graphene. Only 137 publications (slightly more than 0.2%) contained all the three nanomaterials search terms, and this suggests that few piece of research have taken into account carbon nanotubes, fullerenes and graphene at the same time. By contrast, carbon nanotubes seemed to be an important subject for advances in graphene and in fullerenes research, because it markedly appears in publications on these nanomaterials.

Nanotechnology publications increased sharply from 2001 to 2010 displaying an average growth of 13.3% annually, as shown in Figure 5. Nevertheless, publications on carbon nanotubes and graphene grew at higher rates (26.5% and 48.1%, respectively) in the same period. A possible explanation for this result might be that carbon nanotubes have been the target of several technological developments[9,11], and in the case of graphene, there is still a lack of knowledge about this nanomaterial[8,12]. Meanwhile, fullerene publications grew at much lower rates, just 4.0% per year, which suggests a trend to maturity or stagnation, and corroborates the findings reported by Braun, Schubert and Kostoff[27], who analyzed the evolution of fullerene publications from 1985 to 1996. Although the authors suggested that new discoveries concerning fullerenes could cause a further boom in publications, our results do not indicate this occurrence until 2010.

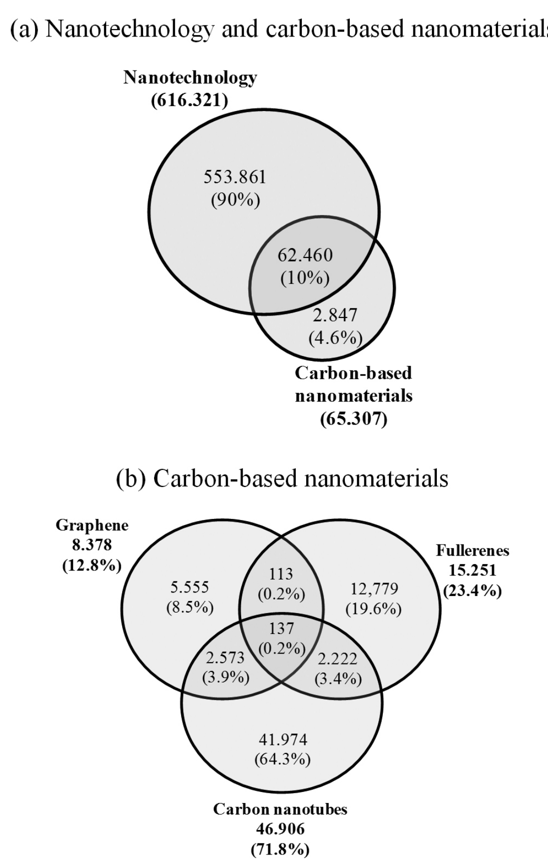

Figure 4. Diagram of publications obtained from crossing the search expression results in the database. Source: Science Citation Index Expanded/Web of Science.

3.2. *Main countries with publications in carbon-based nanomaterials*

From 2001 to 2010, 105 countries had at least one publication in carbon nanotubes, while in fullerene, there were 98, and in graphene, 81. The absence of data from the "country/territory" analytical field was less than 0.3% for all nanomaterials. The USA and China are the leading countries in carbon nanotubes and graphene publications, whereas the USA and Japan are prominent in fullerenes, as presented in Table 2. The top 10 countries, which were also listed as the great supporters of nanotechnology research[2,5], shared a significant part of the total carbon-based nanomaterial publications: 83.0% for carbon nanotubes, 81.4% for fullerene and 79.8% for graphene. Furthermore, Seven countries can be highlighted considering the data from the three tables: the USA, China, Japan, Germany, England, France and Italy (the UK can be evaluated as a whole territory if the countries that belong to this region - England, Scotland, Wales and Northern Ireland - were selected in the "Countries/Territories" and then analyzed together after clicking in *View Records*).

All top five countries showed a rising trend in their publications on carbon nanotubes and graphene, as shown in Figure 6a and 6c. The USA has led annual production of scientific publications on fullerene and graphene since

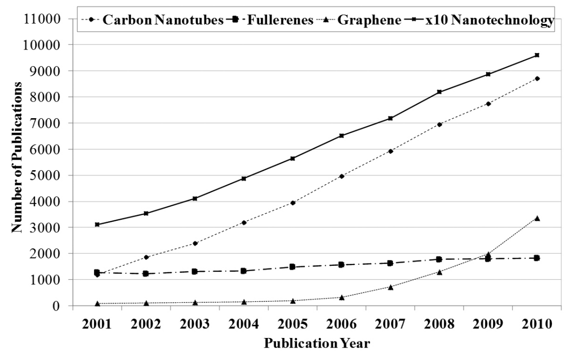

Figure 5. Progress of carbon-based nanomaterials publications from 2001 to 2010. Source: Science Citation Index Expanded/Web of Science.

Table 2. Number of publications, contribution and average growth rate from most productive countries of carbon-based nanomaterials in the period of 2001 to 2010.

	Country	Number of publication	Contribution (%)	Average growth rate (%)
Carbon Nanotubes	USA	12,839	27.4	22.0
	China	11,702	24.9	34.8
	Japan	5,112	10.9	18.8
	Korea	3,499	7.46	39.4
	Germany	2,758	5.88	22.6
	England	2,093	4.46	29.0
	France	2,082	4.44	18.5
	Taiwan	1,600	3.41	37.8
	Italy	1,354	2.89	52.0
	India	1,346	2.87	40.5
Fullerenes	USA	3,008	19.7	5.3
	Japan	2,718	17.8	1.7
	China	2,296	15.1	8.9
	Russia	1,886	12.4	–0.1
	Germany	1,610	10.6	5.1
	France	905	5.93	–5.7
	England	833	5.46	3.1
	Italy	655	4.29	–1.9
	Spain	552	3.62	8.2
	India	461	3.02	12.9
Graphene	USA	2,719	32.5	50.2
	China	1,442	17.2	72.7
	Japan	913	10.9	30.9
	Germany	738	8.81	82.6
	France	470	5.61	56.4
	England	445	5.31	58.6
	Korea	398	4.75	113.1
	Spain	397	4.74	59.9
	Russia	316	3.77	47.0
	Italy	300	3.58	70.5

Source: Science Citation Index Expanded/Web of Science.

2005, whereas for carbon nanotubes, China started leading in 2008 and Korea overtook Japan in 2010. The average growth rate of carbon nanotubes publications was more significant in Italy, India, Korea, Taiwan and China than for the USA, Japan, Germany and France (see Table 2). Besides other possible explanations, this result may be related to the emergence of the S&T system of the former countries[2,13]. Conversely, countries with a more developed S&T, such as the USA, Japan, Germany and France have researched and published significantly on carbon nanotubes since the early '90s, and they may be experiencing a tendency towards maturation and effects of the recent economic crisis. In the case of graphene, in which there is still a lack of knowledge in spite of its potential[8,12], a huge average growth rate of scientific publications on this nanomaterial can be seen, mainly in Korea, Germany, China and Italy, while the USA and China emerge at the forefront of production (Figure 6c).

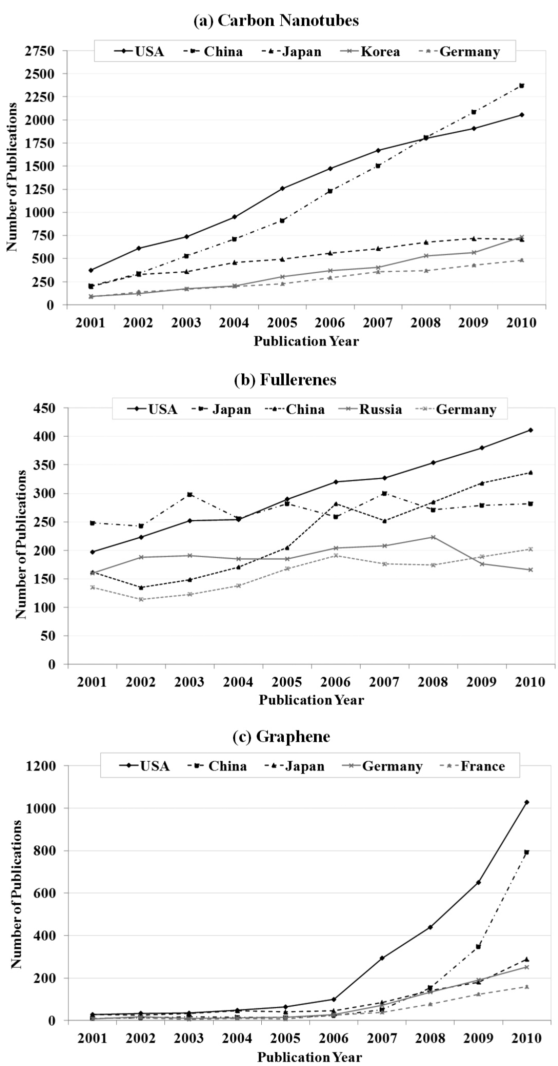

Figure 6. Progress of country publications in carbon nanotubes, fullerenes and graphene from 2001 to 2010. Source: Science Citation Index Expanded/Web of Science.

According to Table 2, low values of the annual average growth are observed for the top countries in fullerenes when compared to the results for other nanomaterials. In the case of Russia, France and Italy, the values of their rates were negative and the number of publications from Russia and France declined gradually from 2001 to 2010. For the USA, China and Germany, a positive rise was still observed while the other countries revealed a stagnation of their scientific publications on fullerene (Figure 6b).

3.3. *Contribution of the most productive institutions in carbon-based nanomaterials*

The ranking of organizations which have contributed to carbon nanotubes research was 7,383 institutions for carbon nanotubes, 3,740 for fullerene and 2,243 for graphene. Less than 0.3% of each nanomaterial data did not have any data from the "Organization-Enhanced" field. The top 10 institutions listed in Table 3 played an important role in the development of each nanomaterial, because they represented 17.8% of the total publications in carbon nanotubes, 24.2% in fullerenes and 23.1% in graphene. The Chinese Academy of Science, the Russian Academy of Science, the University of California and the Japanese S&T Agency were the organizations that contributed enormously to advances in scientific productivity in carbon-based nanomaterials. In addition, the Chinese Academy of Science and the Russian Academy of Science consist of numerous research institutes in their countries and the Japanese S&T Agency supports many research activities, and these facts may influence the results of Table 3.

It can be clearly seen that the growth rates of the top institutions for carbon nanotubes were high, especially for the Japanese S&T Agency, the Chinese Academy of Science and Peking University. In the case of graphene, high growth rate values were observed in all the top institutions, particularly the Massachusetts Institute of Technology and The National Centre for Scientific Research. In contrast, lower growth rates are observed for the main publisher countries in fullerenes, except for the Japanese S&T Agency, the University of California and the Chinese Academy of Science, whose annual number of publications grew by relatively high values in this field. Furthermore, the Russian Academy of Science had a slightly negative rate in the period of analysis, although it displayed the most publications from 2001 to 2010.

3.4. *Main publication journals in carbon-based nanomaterials*

From 2001 to 2010, a list of 1,871 publications in carbon nanotubes was published, while for fullerene, this total was 1,182 and for graphene, just 584. The top 10 journals for each carbon-base nanomaterial are shown in Table 4. Only two of them are highlighted in all three tables, *Physical Review B* and *Applied Physics Letters*, which are also the top productive journals for carbon nanotubes and graphene topics. Additionally, five other journals appeared in the rankings of these two nanomaterials at the same time: *Nanotechnology*, *Carbon*, *Nano Letters*, the *Journal of Physical Chemistry C* and the *Journal of Applied Physics*. In terms of carbon nanotubes and fullerene publications,

Table 3. Number of publications, contribution and average growth rate for the top institutions in carbon-based nanomaterials from 2001 to 2010.

	Institution	Number of publication	Contribution (%)	Average growth rate (%)
Carbon Nanotubes	Chinese Academy of Science	2,344	5.0	26.8
	Tsinghua University	1,106	2.4	22.3
	University of California	1,064	2.3	18.8
	Nat. Inst. of Adv. Industrial S&T	709	1.5	23.5
	Japan S&T Agency	660	1.4	42.9
	Max Planck Society	639	1.4	12.9
	Peking University	632	1.3	26.5
	Russian Academy of Science	623	1.3	24.4
	Massachusetts Inst. of Technology	612	1.3	24.8
	Rice University	580	1.2	25.4
Fullerenes	Russian Academy of Science	1,082	7.1	–0.6
	Chinese Academy of Science	590	3.9	12.1
	Tohoku University	426	2.8	6.9
	Lomonosov Moscow State Univ.	329	2.2	9.3
	Osaka University	322	2.1	6.5
	University of California	306	2.0	18.9
	Kyoto University	305	2.0	9.8
	Japan S&T Agency	280	1.8	28.5
	University of Tokyo	265	1.7	3.3
	University of Erlangen-Nuremberg	253	1.7	9.9
Graphene	University of California	346	4.1	96.6
	Chinese Academy of Science	341	4.1	100.4
	Spanish National Research Council	232	2.8	65.1
	Max Planck Society	194	2.3	75.7
	National University of Singapore	184	2.2	97.7
	Russian Academy of Science	176	2.1	51.8
	Tsinghua University	147	1.8	85.7
	Japan S&T Agency	146	1.7	41.4
	Nat. Centre for Scientific Research	142	1.7	110.6
	Massachusetts Inst. of Technology	138	1.6	114.9

Source: Science Citation Index Expanded/Web of Science.

another two journals were significant: *Chemical Physics Letters* and the *Journal of Physical Chemistry B*.

Physical Review B seems to be the most important journal for carbon-based nanomaterial, because it contains 4.7% of carbon nanotubes publications, 3.3% of fullerene publications and 18.5% of graphene publications. In addition, the top journals for carbon nanotubes accounted for 27.2% of the total number of publications on this nanomaterial, whereas the most productive journal for fullerenes published 23.0% of its publications on the material, and in the case of graphene, 48.9%.

3.5. *Drawbacks and limitations of the proposed method*

Although the method presented in this paper provided an easy way to compile some traditional scientific indicators using the Web of Science analytical feature, some drawbacks and limitations need to be highlighted and discussed. First of all, databases are not static repositories (for example, Web of Science updates weekly) and new data inserted in updates might affect future replication of the indicators. In our case, though, it was not noticed as can be seen from Table 5, which presents the number of publication per year obtained in different date of analysis and using different tools. No significant differences were observed when the total number of publications obtained in September 2012 and April 2013 were compared (they represent less than 0.1% with regards the total number of publications for each nanomaterial). These similar results can be explained in part by the limits imposed on the search, which includes the use of data only from the Science Citation Index Expanded and of four types of document (article, letter, note and review). Moreover, there was a delay of more than twenty months between the date of compiling indicators (September 17th and 18th, 2012) and the final date of the period analyzed (December 31st, 2010). Consequently, the database had had enough time to insert data for the period analyzed (2001-2010). Nonetheless, there would be a high risk of failure if the analysis using the analytical tool took into account periods closest to the date when the indicators were being developed. This drawback for future replication can be minimized if the bibliographic records of the publication are

Table 4. Most productive journals for carbon-based nanomaterials and their contribution from 2001 to 2010.

	Journal	Number of Publication	Contribution (%)
Carbon Nanotubes	Physical Review B	2,221	4.7
	Applied Physics Letters	1,926	4.1
	Nanotechnology	1,481	3.2
	Carbon	1,408	3.0
	Nano Letters	1,226	2.6
	Journal of Physical Chemistry C	1,146	2.4
	Chemical Physics Letters	909	1.9
	Journal of Nanoscience and Nanotechnology	901	1.9
	Journal of Physical Chemistry B	791	1.7
	Journal of Applied Physics	765	1.6
Fullerenes	Physical Review B	504	3.3
	Journal of the American Chemical Society	451	3.0
	Chemical Physics Letters	442	2.9
	Journal of Physical Chemistry B	341	2.2
	Journal of Chemical Physics	320	2.1
	Fullerenes Nanotubes and Carbon Nanostructures	319	2.1
	Applied Physics Letters	303	2.0
	Journal of Physical Chemistry A	289	1.9
	Synthetic Metals	274	1.8
	Chemical Communications	270	1.8
Graphene	Physical Review B	1,554	18.5
	Applied Physics Letters	523	6.2
	Physical Review Letters	462	5.5
	Nano Letters	303	3.6
	Carbon	289	3.4
	Journal of Physical Chemistry C	268	3.2
	ACS Nano	203	2.4
	Journal of Physics Condensed Matter	168	2.0
	Nanotechnology	165	2.0
	Journal of Applied Physics	161	1.9

Source: Science Citation Index Expanded/Web of Science.

downloaded and storage in a local computer. Additionally, Table 5 shows that the number of publications achieved using the analytical tool and bibliometric software were identical, which shows the accuracy of the database feature in counting the publications.

Secondly, there are also some limitations of information available for the analytical tool. For instance, it does not provide lists with the keywords given by authors, total number of citations received, and references cited, etc. The citation analysis, for example, would reveal which countries and institutions were in the line board in carbon-based nanomaterials research. That information can be found in the regular complete bibliographic record exported by the database and parsed using bibliometric software[25]. Another drawback of the analytical tool is the impossibility of inserting directly external data for the analysis, such as the journal impact factor, or improves the precision of indicators cleaning and standardization names of institutions and people, as also noted in other studies[21]. Regarding cleaning and standardization processes, the columns "Organizations" (not standardized) and "Organizations Standardized" from Table 6 show how the use of bibliometric software can improve the precision of the publication count per institution. In fact, Web of Science has also undertaken efforts to improve the standardization of organization names[24], as exemplified from the column "Organizations-Enhanced" from Table 6. This process of grouping different denominations into one standard institution name represents a great challenge due to the fact that some denominations can be wrongly-indicated, especially when author names are considered.

The fact that the database analytical tool does not cross publication data directly or provide charts and network representation is another issue. Despite the risk of failure, such data-crossing can be carried out with some effort and creativity, such as using the three-step procedure described in section 2.2 or the one provided by Osorio and Etieno[22], and the quantified data could be imported into network or chart-drawing software. In this case, bibliometric software would be unnecessary, but its use would speed up the data-crossing process. In the case of the visualization tools, bibliometric approaches usually combine multiple programs

Table 5. Number of publications per year obtained on different dates of analysis and using different features.

	Year of Publication	Analytical Tool	Analytical Tool	Bibliometric Software
		Web of Science	Web of Science	Vantage Point
		17-Sept-12	6-Apr-13	6-Apr-13
Carbon Nanotubes	2001	1189	1189	1189
	2002	1868	1868	1868
	2003	2398	2398	2398
	2004	3193	3197	3197
	2005	3950	3951	3951
	2006	4969	4971	4971
	2007	5928	5937	5937
	2008	6950	6967	6967
	2009	7747	7755	7755
	2010	8714	8730	8730
	Total	46906	46963	46963
Fullerenes	2001	1277	1277	1277
	2002	1229	1230	1230
	2003	1311	1311	1311
	2004	1332	1332	1332
	2005	1493	1493	1493
	2006	1574	1574	1574
	2007	1630	1631	1631
	2008	1777	1777	1777
	2009	1798	1798	1798
	2010	1830	1831	1831
	Total	15251	15254	15254
Graphene	2001	96	96	96
	2002	111	111	111
	2003	134	134	134
	2004	158	158	158
	2005	192	192	192
	2006	329	329	329
	2007	718	719	719
	2008	1296	1300	1300
	2009	1982	1982	1982
	2010	3362	3364	3364
	Total	8378	8385	8385

Source: Science Citation Index Expanded.

Table 6. Comparison of total number of publications from institutions in carbon nanotubes from 2001 to 2010 using the analytical tool ("Organizations" and "Organizations-Enhanced" columns) and bibliometric software ("Organizations Standardized" columns).

Institution Name	Organizations	Organizations Standardized	Organizations-Enhanced
Tsinghua University	595	1105	1105
University of California	333 (Berkeley)	1066	1066

Source: Science Citation Index Expanded.

to perform analysis, calculation and representation as there is no unique software able to fulfill all the requirements and bibliometric analysis known[18]. Furthermore, sophisticated bibliometric approaches, such as text mining, measurement of impact using citations, cluster analysis, network metrics and interdisciplinary linkages, are not possible using the analytical feature[9-17].

4. Conclusion

In this study, scientific publication on carbon-based nanomaterials was analyzed using the indicators developed from the Web of Science analytical tool. To sum up our findings, graphene and carbon nanotubes publications rose at higher rates than those for the nanotechnology field from 2001 to 2010. On the other hand, the performance of scientific publications in fullerenes was significantly lower and suggested maturation or stagnation of research concerning this nanomaterial. The top countries shared 83.0%, 81.4% and 79.8% of the total number of publications for carbon nanotubes, fullerenes and graphene, respectively, and the USA proved to be the main country of accumulated scientific productivity (publications) throughout the period investigated, although China overtook the American leadership in (publications on) carbon nanotubes publication from 2008. Institutions from the USA, China, Japan and Russia played an important role in the advances of the nanomaterials analyzed with emphasis on the Chinese Academy of Sciences, the Russian Academy of Sciences, the University of California and the Japanese S&T Agency. Among the journals which have the most scientific publications, the *Physical Review B* and the *Applied Physics Letters* can be highlighted as the main vehicles to publish carbon-based nanomaterials research. These outcomes support our hypothesis that the Web of Science analytical tool and the procedures used are helpful for researchers from any area in developing important indicators. They may be applied to other nanotechnology dimensions or knowledge areas to understand the worldwide and local dynamics of scientific productivity in publications.

By making the analytical tool available, which has the advantages of database wide coverage, indexing quality and worldwide use, the Web of Science has also become a supplier of highly valuable information and indicators. However, we have discussed a number of important limitations and drawbacks that need to be considered when using this database feature. First of all, future replication of indicators may be difficult when analysis considers periods close to the date of compiling indicators. Secondly, the analytical tool does not consider the citation and collaboration data of a publication, which are useful in supporting analysis of quality and mapping joint efforts of countries and institutions, respectively. Other issues regard the fact that the analytical tool does not directly cross data from different fields and that cleaning and standardization processes for names are not available, besides the advances already incorporated into the database. Finally, the analytical feature does not provide information from the author's keywords or terms extracted from the title and abstract, which can be advantageous to understand better where the research is directed. Thus, we recommend the use of the Web of Science analytical tool only as a starting point and for general performance examination. In cases of deep understanding, advanced methods and specialized software should be used.

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