

The influence of European Framework Programmes on scientific collaboration in nanotechnology

María-Antonia Ovalle-Perandones · Juan Gorraiz · Martin Wieland · Christian Gumpenberger · Carlos Olmeda-Gómez

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Abstract This study deals primarily with the effect of certain European Framework Programmes on EU-27 member states' publication output in nanotechnology, with a focus on their scientific collaboration over the last ten years. The study was conducted at three levels (category, journal and publication). The aim was to verify whether the newly launched category is sufficiently complete, as well as to identify the most prominent journals and compare the EU-27 member states' output to world production. Snapshots of European networking are also provided for three key dates (2001, 2006 and 2011) to ascertain the positions of emerging and central countries and analyse their variations over time. The results confirm the speedy development in the field and the importance of the EU-27s world role. They corroborate the close correlation between funding and increased output and the intensification of collaboration among member states. Finally, the information contained in the “Funding Agency” field in the Web of Science database was also compiled, with a view to substantiating the validity of the estimated impact of EU-funding programmes on member states' scientific output.

Keywords European Framework Programmes · Scientific collaboration · Nanotechnology

Introduction

Collaboration is a key issue in the European Union's (EU) Framework Programmes (FP) (Van Leeuwen and Tijssen 2007). The Union has consequently developed a specific

M.-A. Ovalle-Perandones (✉) · C. Olmeda-Gómez
Department of Library of Information Science, Carlos III University of Madrid,
C/Madrid, 128, 28903 Getafe, Madrid, Spain
e-mail: antonia.ovalle@uc3m.es

J. Gorraiz · M. Wieland · C. Gumpenberger
Bibliometrics Department, Vienna University Library, University of Vienna,
Boltzmannsgasse 5,
1090 Vienna, Austria

programme for “Cooperation”,¹ that supports all manner of cooperative research conducted transnationally and whose ultimate aim is to gain or consolidate leadership in key areas of science and technology.

The present study deals with nanotechnology, a new thematic area that has appeared in the two latest Framework Programmes, FP6 and FP7. The importance and timeliness of this field is corroborated by the existence of analogous support strategies elsewhere, such as the National Nanotechnology Initiative in the USA, the Nanotechnology Revolution in China, the Nanotechnology Initiative in Japan and Russia’s “Rusnano”.

To date, a number of insightful studies have dealt with the economic and similar effects of R&D funding strategies since the FPs were launched (Brechi and Malerba 2011) or the difficulties and challenges faced when analysing these processes (Luukkonen 1998). The EU’s official recognition of the relevance of bibliometric indicators for policy purposes in the twentieth century (Delanghe et al. 2011) encouraged scientometric analysis. Some of the resulting papers focused on nanotechnology as an emerging area of scientific research (Hullmann 2007) or a field for technological development (Chen and Roco 2009).

The research questions posed were:

1. In which degree does the delineation of the field influence the bibliometric results?
2. Which journals carry papers on nanotechnology?
3. What percentage of world-wide nanotechnology output is accounted for by the EU?
4. Have collaboration rates and patterns (emerging/central) among EU-27 member states changed visibly?
5. Have European Framework Programmes actually impacted or shaped scientific output in nanotechnology or the intensity of collaboration among member states?

The results of this study may also be useful for organisations interested in furthering scientific cooperation and particularly for establishing alliances with countries reputed for their nanotechnology expertise (Luukkonen et al. 1993).

Methodology

As approach we have selected a combination of bibliometric methods with social network analysis (SNA) as recommended in previous studies for similar purposes (EPEC 2011).

Data were retrieved and analysed at three levels:

1. *Category* the structure and evolution over the last 5 years of the Web of Science (WoS) category “NanoScience and Nanotechnology” were analysed. The data used for this study were drawn from Thomson Reuters’ “Journal Citation Reports (JCR)”.
2. *Journal* the variations in the impact in the journals assigned to this category were studied. The data were retrieved from JCR. International collaboration data for these journals were additionally obtained from SCImago Journal & Country Rank (SJCR), except for four journals where the information was missing in this data source.
3. *Publication* the data source is the “Science Citation Index Expanded (SCI-EXPANDED)” part of the Thomson Reuters WoS. The first step, performed in June 2012, was to retrieve all relevant articles. The field of research (Leydesdorff 2008) was more precisely delineated by compiling several samples and discussing the results (see Delineation below).

¹ http://cordis.europa.eu/fp7/cooperation/home_en.html. Last review: 20 Feb 2013.

The variation in the EU's share of world output was analysed for two samples covering the period 2001–2011. In this exercise, all publications listing an affiliation in at least one EU-27 member state (country)² were retrieved.

The focus was placed on three decisive years: 2011, the fifth year into FP7; 2006, the last year of FP6 and 5 after its launch; and 2001, the starting date for FP6. Collaboration among European Union member states was analysed for one sample in these selected years, generating the respective network outlays to determine the roles of emerging and central countries.

The network for 2001 comprised 836 records, for 2006, 2,290 and for 2011, 4,430. All records were downloaded from WoS and subsequently mapped with Bibexcel and Pajek.

Finally, the findings were tested for a possible correlation with EU funding efforts. Here also, the information source was WoS data records, which since 2008 include a field headed "Funding Agency". All the EU-related entries in that field (FO), such as Nandos, SANDIE or Marie Curie, were identified for the years 2008–2011. Over 100 entries were then pooled in a general search string and used to retrieve all the articles funded by the EU in each of those years.

Delineation of the research field

The research field analysed, in this case nanotechnology, was carefully delineated in this study in order to improve recall and precision (Meyer et al. 2001). Most previous studies (Schummer 2007; Leydesdorff and Zhou 2007; Tang and Shapira 2011; Rueda et al. 2007) used a rather simplistic and consequently incomplete search string to retrieve all relevant documents or articles from the WoS: "TS = nanotechnolog*" (Sample 0). One of the most typical pitfalls of WoS-based bibliometric analyses stems from the failure to realise that this database has no thesaurus-like descriptors. Consequently, the high precision but low recall³ search results delivered by single term search strings are inappropriate for this type of analyses. To improve recall, potentially relevant terms must be combined in the search strategy, a far from trivial and often arduous procedure. Four approximations were used in this study to mitigate the problem and collect and compare more complete samples than sample 0.⁴

In Sample 1 a set of "core" nanotechnology journals replaced the search terms. Since 2005, WoS has had a category of its own headed "Nanoscience and Technology" that lists approximately 65 journal titles. All the publications in the SCI-EXPANDED listed under this category and published from 2001 to 2011 were collected.⁵ The drawback to Sample 1 is its broadness, however, since many articles published in the journals in this category are not directly concerned with nanotechnology.

Sample 2 is a combination of search terms collected from the controlled vocabularies (thesauri) available in alternative data sources. In light of the hierarchical structure of

² http://europa.eu/about-eu/countries/index_en.htm. Last review: 20 Feb 2013.

³ In information retrieval, precision is the fraction of retrieved items that are relevant, while recall is the fraction of relevant items that are retrieved. Both are therefore based measure of relevance http://en.wikipedia.org/wiki/Precision_and_recall. Last review: 20 Feb 2013.

⁴ Following an iterative process to identify relevant identifiers has also been tested, however, this approach turned out to be very cumbersome and did not improve the quality in comparison to samples 2 and 3.

⁵ Since 2012, WoS enables the search of all the publications related to a WoS subject category (WS =). Otherwise, the search must be done for all journal titles assigned to the corresponding WoS Category.

thesauri, searches can be conducted at various levels of specificity. All the controlled terms included in the following controlled vocabularies were consequently collected: (1) the Information Services for the Physics and Engineering Communities' (INSPEC) thesaurus, (2) the National Library of Medicine's Medical Subject Headings (MeSH), (3) the EU's EuroVoc (multilingual and multidisciplinary), (4) the National Center for Biomedical Ontology's (NCBO) controlled vocabulary and (5) the International Patent Classification (IPC).⁶

All five databases explicitly include nanotechnology as a descriptor. That perfected the selection of keywords for searching the WoS and facilitated the creation of an appropriate search string.⁷

Even though Sample 2 drew a fairly satisfactory picture of the research field studied, the exclusion from the search string of the related terms proposed in the thesauri consulted might be challenged. The Sample 2 search string was therefore enlarged to include all the related terms in the aforementioned thesauri⁸ (Sample 3). The prefix “nano*” was added to such terms to reduce noise. This global search string was used from the very outset of the study to estimate the maximum volume of publications (maximal recall).

Sample 4, the intersection between Samples 1 and 3 (Boolean “AND”), also proved to be useful as an estimate of the overlapping.

Table 1 compares the items and articles retrieved for the years 2001–2011 in the five samples. Glaring differences were observed. Sample 0, based on the search criterion used in previous studies, delivered only a partial and very limited view (recall) of the research field: the number of publications was a mere one-tenth of the number retrieved with controlled vocabulary-based searches.

The intersection between samples 1 and 2 contained 20,297 records (Items, world, 18,538 articles), the implication being that only 20 % of the records retrieved using controlled vocabulary were included in the respective WoS category and only 14.5 % of the documents assigned to this category actually had descriptors relevant to this research field.

The variations in two of these samples 1 and 2, over the last 10 years are described fully in the next section. Sample 1 (category) and Sample 2 (thesaurus) were used for the analyses and mapping reported here. The analysis will be extended to Sample 4, the Boolean intersection of samples 1 and 3, in a subsequent study to compare the results.

⁶ (1) <http://www.theiet.org/resources/inspec/about/>, (2) <http://www.nlm.nih.gov/pubs/factsheets/mesh.html>, (3) <http://eurovoc.europa.eu/drupal/>, (4) <http://bioportal.bioontology.org/ontologies/47638?p=terms> and (5) <http://www.wipo.int/classifications/ipc/en/>. Last review 26 Feb 2013.

⁷ The resulting search string is: TS = (“nanotechn* or nano-techn*”) OR TS = (nanobiotechnolog* OR nanobiotechnolog* OR nanocontact* OR nanocontact* OR nano-structure* OR nano-structure* OR nano-electric* OR nano-electric* OR nanoelectromechanical device* OR nanosensor* OR nanofluid*) OR nanoelectronic* OR nano-electronic* OR nanofabrication* OR nano-fabrication* OR nanolithograph* OR nano-lithograph* OR nanomagnetic* OR nano-magnetic* OR nanomagnetism* OR nano-magnetism* OR nanomechanic* OR nanomechanic* OR nanoindentation* OR nano-indentation* OR nanomedicine OR nano-medicine OR nano-optic* OR nano-optic* OR nanopatterning OR nano-patterning OR nanophotonic* OR nano-photonic* OR nanopositioning OR nano-positioning).

⁸ TS = (atomic force* microscop* OR bio-inspired material* OR bioinspired material OR fullerene device* OR integrated circuit* technolog* OR lithograph* OR microchemist* OR microchip analytical procedure* OR microfabrication* OR micromechanical device* OR miniaturization* OR nanobridge* OR nano-bridge* OR nanocomposite* OR nano-composite* OR nanofiber* OR nano-fiber* OR nanofiltration* OR nano-filtration* OR nanomaterial* OR nano-material* OR nanoparticle* OR nano-particle* OR nanopore* OR nano-pore* OR nanotube device* OR nano-tube device* OR nanoscience OR nano-science OR nanotube* OR nano-tube* OR nanowire* OR nano-wire* OR optical trap OR optical tweezer* OR scanning tunneling microscop* OR single electron transistor* OR superconducting OR VLSI).

Table 1 Documents and research articles obtained for each sample

Retrieved documents	Sample 0 TS = (nanotechnolog* OR nanotechnolog*)	Sample 1 Journals	Sample 2 Thesauri	Sample 3 Thesauri + related terms	Sample 4 Samples 1 AND 3
Items, world	13518	138306	100621	364006	58923
Articles, world	9479	131186	89752	329206	55465
Article, EU-27	2689	40392	27534	90537	14590

Table 2 WoS category “Nanoscience and Nanotechnology”, 2005–2010

	Aggregate IF	Median IF	No of journals	No of citable papers	No of ref./citable papers	Total citations
Min	2.24	1.39	27	7315	23.3	80667
Max	4.15	2.04	64	20534	34.6	420212
%Growth	85 %	47 %	137 %	181 %	48 %	421 %
%Growth/ year	14.20 %	7.80 %	22.80 %	30.10 %	8.10 %	70.20 %

Results

Category

Since its introduction in 2005, the WoS Journal Category “Nanoscience and Nanotechnology” has grown steadily in terms of both publications and citations (see Table 2, Gorraiz et al. 2012). The number of journals rose from 27 in 2005 to 64 in 2010.

The near absence of any explicit “review journals” in this category is an interesting revelation.

Figure 1 shows the annual variations in the rate of international collaboration determined for the nanotechnology journals in Sample 1⁹. The average value (see continuous line in Fig. 1) increases constantly between 2001 and 2010.

The green columns in Fig. 2 represent all journals with average international collaboration values higher than 20 (58.3 % journals). For the journals in orange average international collaboration is less pronounced (below the threshold of 20 (41.7 % journals).

Journal

The journal “Nature Nanotechnology” (ISSN: 1748-3387), launched in 2006, with an IF that increased from just under 21 in 2008 to about 30 in 2010, heads the list. Data from JCR show that the IF for all the top journals in this category (with an IF of over 5) gradually climbed and that eight new journals launched between 2005 and 2008 quickly rose to the top of the impact list.

⁹ Based on data collected from SCImago Journal & Country Rank (SJCR). <http://www.scimagojr.com/>. Last review 18 Feb 2013.

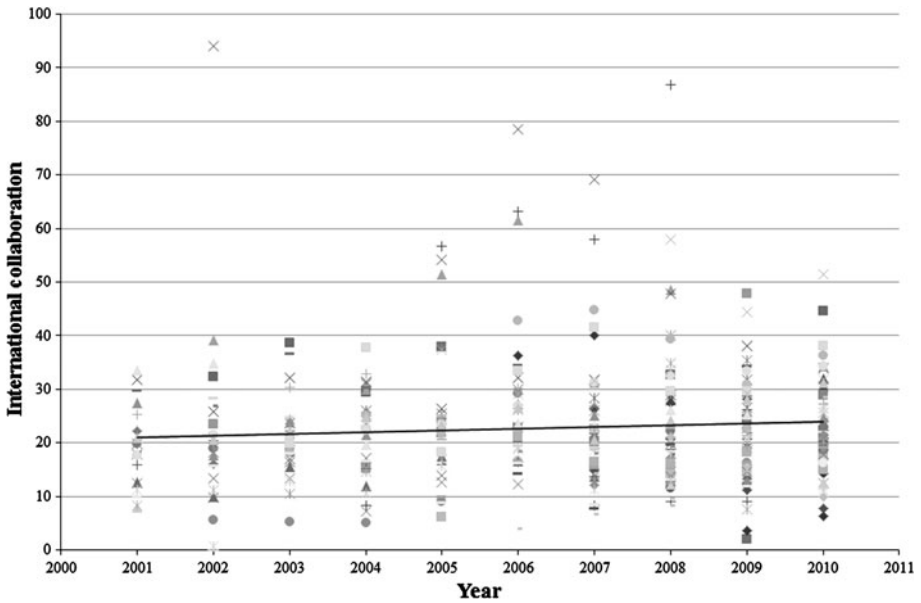


Fig. 1 Rate of international collaboration in journals in the “Nanoscience and Nanotechnology” category, 2001–2010

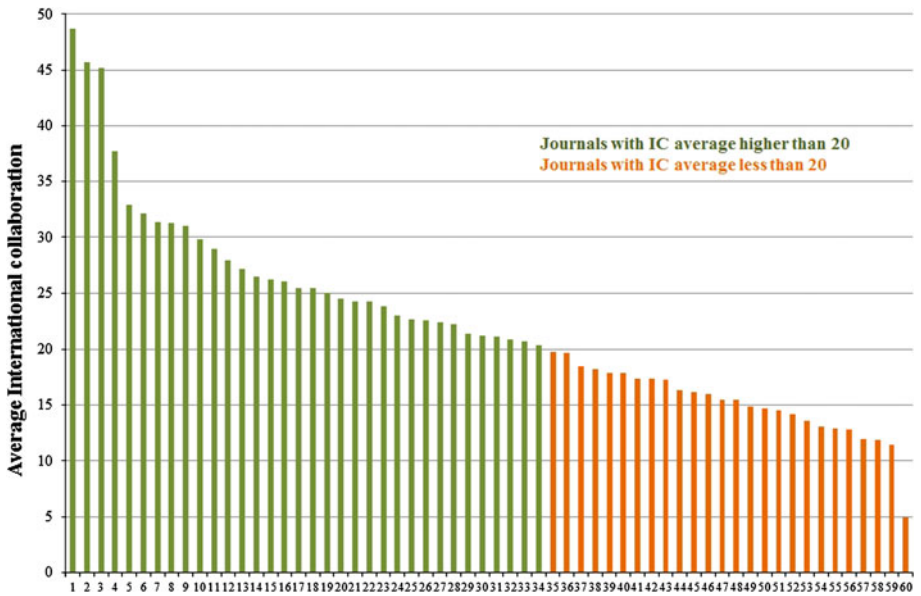


Fig. 2 Average international collaboration observed for journals in the “Nanoscience and Nanotechnology” category (2001–2010)

In addition, journal distribution in samples 1 and 2 was analysed in detail to identify the most prominent journals dealing with Nanotechnology. Table 3 lists the journals (with over 1,000 articles on the subject) in Sample 2 (thesaurus) that were also found in Sample

Table 3 Presence of the sample 2 top journals in sample 1

Journal in sample 2 (more than 1,000 articles)	Journal in sample 1
Applied physics letters	No
Nanotechnology	Yes
Physical review B	No
Journal of applied physics	No
Journal of physical chemistry C	Yes
Nano letters	Yes
Langmuir	No
Journal of alloys and compounds	No
Journal of nanoscience and nanotechnology	Yes
Angewandte chemie international edition	No
Journal of crystal growth	No
Journal of the american chemical society	No
Journal of materials chemistry	No
Applied surface science	No

1. Only four of the 14 journals in Sample 2 that carried over 1,000 nanotechnology articles were listed in Sample 1 (WoS category). Those 14 journals together accounted for almost one-third of all the records retrieved in Sample 2.

Publication (article)

Sample 1

For this study, all the articles with at least one affiliation in a EU-27 country published in the journals listed under this category were retrieved and analysed.

Figure 3a attests to the steady rise in the number of articles with at least one EU-27 affiliation. Since this growth was slower than for the world as a whole, output in this area of research rose in many other countries outside the European Union over the last 11 years. Database coverage of scientific production may have also become more complete in this period.

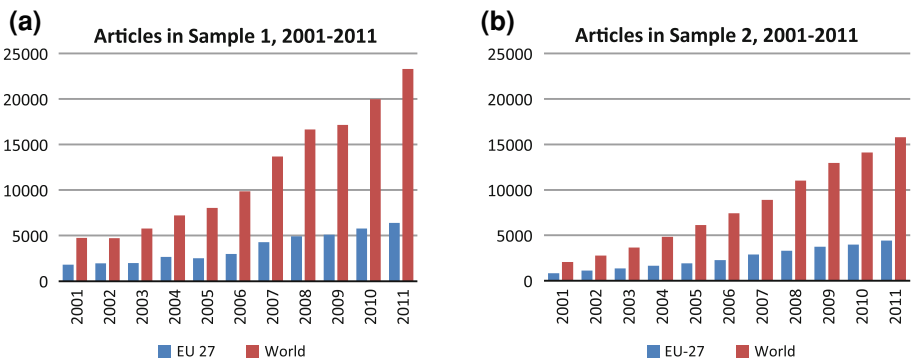


Fig. 3 Number of articles on nanotechnology with at least one affiliation in a EU-27 country versus world output **a** Sample 1. **b** Sample 2

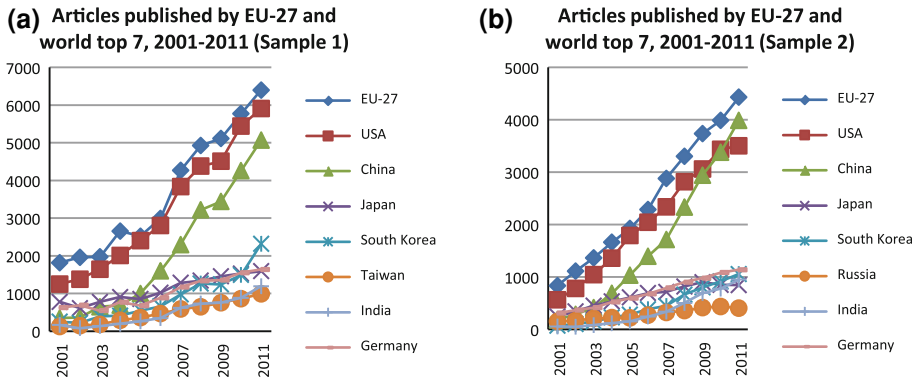


Fig. 4 Nanotechnology article output by all EU-27 countries versus production in the world's seven most productive countries **a** Sample 1. **b** Sample 2

To have a more detailed picture of the world production, the timeline of all EU-27 countries in comparison with the top seven more active countries of the world has been considered.

EU-27 production is compared to the production of the seven most active countries in the world in Fig. 4a. German output is represented twice, inasmuch as it is both a EU-27 and a top producer country. Note that growth was similar in the USA and China and the upward trend recorded for South Korea, the third most active country in this field in 2011.

Sample 2

The same analyses were conducted for Sample 2 with similar results (see Figs. 3b and 4b). The EU-27 retained its leadership and China overtook the USA (Fig. 4b), while Taiwan's fifth place in Sample 1 was taken over by Russia in Sample 2 (Fig. 4a, b).

The trend in each EU-27 member state was also analysed (Fig. 5). In keeping with its position among the world leaders, Germany had the highest Nanotechnology output and maintained its predominance in Europe across the entire period. The steepest rises were observed for France, followed by England¹⁰, Italy and Spain. Of the countries with an output of under 100 articles per year, performance was highest for Portugal, Ireland and Scotland.

Partnering networks in three decisive years for sample 2 (thesauri)

Collaboration among European Union countries was analysed for three selected years (2001, 2006 and 2011), using network layouts to ascertain the roles played by emerging and central countries. The Kamada–Kawai algorithm was used to draw the layouts (Kamada and Kawai 1989). In Figs. 6, 7 and 8, the blue nodes (light grey) represent non-EU and the red circles (dark grey) EU-27 countries. Vertex size is proportional to the respective country's scientific production. The three networks depicted are deemed to be "small" because they had fewer than 100 vertices (Börner et al. 2007). The number of countries (nodes) publishing papers on nanotechnology grew from 51 in 2001 to 83 in

¹⁰ The four UK countries (England, Northern Ireland, Scotland and Wales) were considered separately in this analysis.

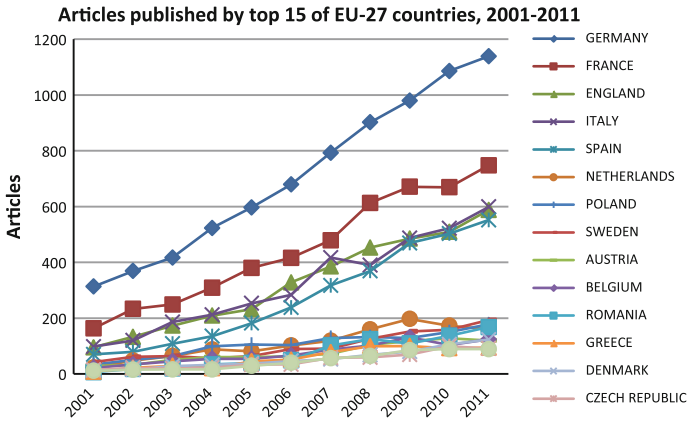


Fig. 5 Output in nanotechnology by EU-27 country, 2001–2011 (Sample 2, Top 15)

2011. The presence of EU-27 countries declined from 45 % in 2001 to 39 % in 2006 and 31 % in 2011, inferring that EU-27 countries constantly sought new third-party partners for international collaboration. The only EU country that failed to conduct nanotechnology research in collaboration with at least one other country in 2006 and 2011 was Malta.

General measures of network structure were calculated and are summarized in Table 4. The total number of lines is the total number of relationships (collaboration) between the countries. The density is a measure of the proportion of the maximum possible number of lines and the actual number of lines in the net (Scott 2000), for example, a density value of 0.16 means that 16 percent of all possible relations are present.

The degree centrality of a vertex is the number of lines incident with a vertex, that is, the number of its neighbors (see centrality measures and Table 5). The average degree of all vertices (see Table 4), based on this centrality measure, is a better measure than density, since it is independent from the network size.

Table 4 shows that the networks in nanotechnology are getting denser through this period.



Fig. 6 Collaboration network in nanotechnology (2001)



Fig. 7 Collaboration network in nanotechnology (2006)



Fig. 8 Collaboration network in nanotechnology (2011)

Table 4 Network measures (2001, 2006, 2011)

Network measures	2001	2006	2011
Number of vertices	51	67	83
Vertices EU-27	22	26	26
Number of lines	206	405	726
Density	0.16	0.18	0.21
Average degree	8.07	12.09	17.49

These data were supplemented with other measures of network structure, like centrality measures, the most fundamental and frequently used ones (Nooy et al. 2004; Newman 2008).

Table 5 Top ten countries by degree centrality (2001, 2006, 2011)

2001			2006			2011		
Country	Deg.	Closen.	Country	Deg.	Closen.	Country	Deg.	Closen.
Germany	31	0.725	Germany	50	0.805	France	64	0.820
France	31	0.725	France	45	0.759	Germany	58	0.774
USA	27	0.685	UK	41	0.725	Italy	54	0.745
UK	24	0.649	USA	39	0.725	Spain	53	0.739
Italy	21	0.617	Spain	32	0.660	UK	52	0.732
Spain	21	0.617	Italy	31	0.653	USA	51	0.726
Russia	18	0.602	Japan	30	0.647	Sweden	42	0.672
Sweden	15	0.602	Poland	26	0.623	Poland	38	0.651
Japan	13	0.568	Sweden	26	0.623	PR China	37	0.646
Denmark	13	0.574	Russia	25	0.617	Romania	35	0.636

Degree centrality has already been discussed before. Furthermore the closeness centrality of country A is the reciprocal of the mean geodesic distance from country A to every other country. One country with a high value of closeness will be central because it is near to a considerable number of countries.

For any vertex the betweenness centrality is the proportion of geodesics between pairs of other vertices that include this vertex. If we imagine information flowing between countries in the network and always taking the shortest possible path, then it measures the fraction of information that will flow through the considered vertex. Betweenness enables the identification of countries that have the ability to connect.

Table 5 shows the top ten countries according to their degree centrality values (Deg.) and in the right column, their closeness values (Closen.). Degree and closeness rose steadily. Germany and France consistently took the top positions in all years. Note that Romania entered the top ten to the detriment of Russia in 2011. Rising centrality values for a node (here, a country) in a network in which the number of nodes continues to grow means that the country’s position has improved.

The last centrality measure considered in our study is the betweenness centrality (Newman 2008). The results are shown in Table 6.

Table 6 Top ten countries by betweenness centrality (2001, 2006, 2011)

Country	2001	Country	2006	Country	2011
France	0.242	Germany	0.248	France	0.162
Germany	0.225	France	0.147	Germany	0.140
Spain	0.135	UK	0.119	Spain	0.094
USA	0.133	USA	0.082	Italy	0.090
UK	0.094	Spain	0.068	UK	0.058
Italy	0.066	Italy	0.045	USA	0.049
Belgium	0.040	Japan	0.033	Poland	0.038
Sweden	0.039	Belgium	0.033	Sweden	0.033
Russia	0.020	Poland	0.026	Greece	0.026
Finland	0.018	Sweden	0.024	Romania	0.024

Table 7 Incidents of partnering between pairs of countries (2001, 2006, 2011)

2001			2006			2011		
Germany	USA	30	Germany	USA	88	Germany	USA	123
Germany	Russia	30	France	Germany	52	UK	USA	96
UK	USA	18	UK	USA	51	France	Germany	80
France	USA	14	Germany	Russia	37	Germany	PRChina	68
France	Germany	14	France	Italy	34	PRChina	UK	64
France	UK	12	France	USA	32	France	USA	58
France	Japan	10	France	Spain	31	France	Spain	57
Italy	USA	10	Germany	Spain	31	Germany	Spain	55
198 country pairs w/less than 10 incidents			397 country pairs w/less than 31 incidents			718 country pairs w/less than 54 incidents		

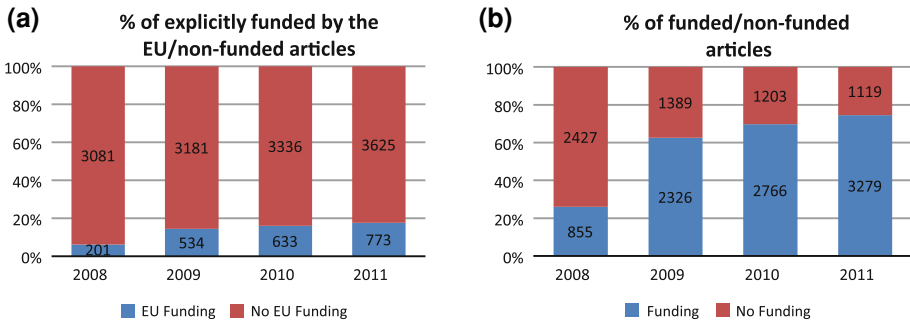
**Fig. 9** Timeline 2008–2011 of **a** the percentage of funding/no funding explicitly by the EU and **b** the percentage of funding/no funding articles

Table 7 in turn shows the pairs of countries that partnered most frequently. As mentioned earlier, although the number of nodes grew over the years, the number of pairs also rose, making the network much denser.

Funding analysis for sample 2 (thesaurus)

Of the 15,364 articles published by the EU-27 between 2008 and 2011, 9,226 (about 60 %) were funded (FA field not empty) and 2,141 (about 14 %) were explicitly funded by the EU. By comparison, of the 53,925 articles published world-wide in that same period, 34,902 (about 65 %) were funded (FA field not empty). Figure 9a shows that EU funding grew from 5 % of the total papers on nanotechnology published in 2008 to 18 % in 2011.

As Fig. 9b shows, a high percentage of the research conducted in this field was funded (almost 75 % of the EU-27 articles were funded in 2011), while EU funding was provided in less than one-fourth of the total number of funded articles.

Finally, for the publication year 2011, the country distribution of the EU publication output has been compared for explicitly EU funding and no funding (see Table 8). The results show that the activity percentage of almost all European countries is higher, when the research was explicitly funded by the EU, while the activity intensity of the most important non-European actors is decreasing (see bold data, e.g. USA and China). Spain

Table 8 Percentage of papers with EU funding versus non EU funding for each EU-27 country and the top four non-European countries (2011)

Country	(%) EU	(%) Non-EU
Germany	24.64	26.00
France	18.16	16.48
United Kingdom	16.99	15.58
Italy	15.43	13.15
Spain	19.71	10.81
USA	8.56	10.48
Peoples R China	3.50	5.28
Sweden	5.97	4.10
Poland	4.80	3.91
Romania	3.37	3.91
Netherlands	5.19	3.27
Austria	2.85	2.70
Belgium	2.98	2.67
Denmark	3.50	2.53
Japan	1.95	2.81
Switzerland	4.41	1.98
Portugal	3.24	2.09
Greece	5.19	1.51
Czech Republic	1.69	2.20
Finland	2.33	1.93
Ireland	1.43	1.98
Slovenia	1.30	1.07
Hungary	1.43	0.77
Bulgaria	0.52	0.83
Latvia	0.91	0.33
Lithuania	0.78	0.36
Slovakia	0.52	0.28
Estonia	0.52	0.08
Cyprus	0.13	0.11
Luxembourg	0.00	0.11
Malta	0.00	0.03

and Greece are profiting the most. Germany is one exception, but this is probably due to the national funding programme DFG. Interesting is also that some newcomers (like e.g. Romania, Czech Republic and Bulgaria) are not yet increasing their activity through EU-funding.

Conclusions and outlook

This study reveals, firstly, the importance of field delineation when the data source used is the WoS, where subject categories are assigned to journals but not to individual articles and controlled vocabulary is not applied. Indeed, only 14 % of the papers listed under the

WoS subject category “NanoScience and NanoTechnology” were actually found to contain descriptors relevant to this research field and only 20 % of the records retrieved using a controlled vocabulary search were included in the category.

The selection of the core journals assigned to this category was also observed to be highly questionable: only four of the top 14 journals (which accounted for one-third of the total number of articles retrieved) identified using controlled vocabulary were listed in the WoS category.

The correct choice of a search strategy plays a key role in bibliometric studies and may impact the results significantly. Prior studies on nanotechnology have used very simple “search strings” whose precision was indisputably high but whose low recall was an obstacle to obtaining a full picture of the research field. More sophisticated methods combining textual components with citation-based techniques will certainly improve the delineation process (Zitt and Bassecouard 2006; Glaenzel et al. 2007; Glaenzel 2012).

The present analysis, conducted on two samples (journal category and thesauri), also shows that nanotechnology is an emerging field not only in the EU but the world over. Activity has been rising steadily in nearly all countries, lowering the EU-27s world-wide weight. A more detailed comparison of the Union to the seven most active non-European countries in the field, namely the USA, China, Japan, South Korea, India, Taiwan and Russia, shows that the EU-27 is the world leader in terms of number of published articles and second only to China in rate of growth. This can be attributed primarily to the steady rise in activity in Germany, which ranks fourth or fifth world-wide in the field. In addition to Germany, France, the UK, Spain and Italy all publish over 200 articles per year and their output follows a clearly upward trend.

With intensified collaboration among the EU-27 nations, the structure of the yearly networks has grown increasingly dense. The most central EU-27 countries also have the highest output: Germany, France, UK, Spain and Italy. They constantly enlist new countries in collaborative studies without forfeiting their central and predominant position. France’s number one position in betweenness and (in 2011) even degree centrality, overtaking Germany, and the appearance of Romania in the top ten to the detriment of Russia are findings worthy of particular note.

A detailed analysis of the most frequent pairs of collaborating countries shows that Germany’s and the UK’s world leadership positions are obviously related to their intense partnering with the USA. In keeping with the new international landscape, Germany, which in 2001 collaborated as intensely with Russia as it did with the USA, now favours China instead as one of its most frequent Nanotechnology research partners. Its collaboration with France has also grown steadily, consolidating this pair as the most prolific partnership within the EU.

An analysis of the data retrieved from the WoS “Funding Agency” field sheds some light on this question. An extremely high percentage of nanotechnology research is funded: 65 % of the world articles and 60 % of the EU-27 papers published between 2008 and 2011 benefited from funding, which is consistent with the topicality of the field.

The findings also show that while the proportion of EU-27 publications funded explicitly by the EU rose from 5 % in 2008 to 18 % in 2011, these papers accounted for less than one-fourth of the total funded articles dealing with nanotechnology published in the period analysed. Therefore, national funding programmes and other initiatives (such as DFG¹¹ programmes, for instance) may play a very important role that merits further and more detailed study. The numbers in this regard speak for themselves: in 2011 almost 75 %

¹¹ Deutsche Forschungsgemeinschaft (DFG, <http://www.dfg.de>. Last review 15 Feb 2013).

of the EU-27 articles on nanotechnology were funded but only about one-fourth were explicitly funded by the EU.

However, these data—especially as regards 2008 (the year the field was introduced)—should be interpreted with caution. The WoS entries have not yet been normalised and data cleaning is cumbersome. Moreover, little is presently known about how complete or accurate these WoS data are.

By way of summary, the present paper provides an overview of output patterns in nanotechnology research. Our study on collaboration strictly within the EU-27 sheds considerable light on each EU member state's specific position and respective dynamic or static behaviour in one of the fields most recently included in the EU FP.

In further studies it will be necessary to focus on the impact issue of funding programmes, not only basing on trends and correlations but also trying to evidence their causal impact.

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