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Analysis of Europe's scientific production on renewable energies

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ABSTRACT

An overview is given of research in the major countries of Europe in the area of renewable energies. The analysis used the Scopus (Elsevier) database of scientific literature, calculating bibliometric indices (primary production, average citations per document, percentage variation, SJR, etc.) for the geographical domain of Europe during the period 2002–2007. The aim of the study is to supplement previous works on the subject which have mostly been limited to a particular type of energy without addressing the area as a whole, as well as to expand their methodological approaches in both the data retrieval strategy and the calculation of indices. The results show Europe to be well positioned globally in this scientific field – in production, in citations, and in impact.

1. Introduction

The science and technology of sustainable and renewable energies are indispensable for the future of our economy and society. There has been a major growth in research effort to advance the development of these energy sources [1]. However, the trends in renewable energy systems have received attention in only a few, but nevertheless interesting, scientometric studies [1–7]. These studies have given a first idea of progress in science and technology in this field [8], and we shall briefly discuss them in the following paragraphs.

Thomas [2] evaluates the work of research groups in the field of biomass, considering areas outside the U.S. and the E.E.C. Two key elements are considered: the measure of scientific productivity, and an examination of the factors that affect the functioning of research.

Uzun [3] compares the research results and priorities of 25 countries in renewable energy for the periods 1996–1997 and 1998–1999, using as measures the numbers of publications and their increase, and the research priority index.

Hassan [4], recognizing the part played by science and technology in the development of fuel cells, characterizes the evolution of the structure of these cells in the 1990s on the basis of patent and scientific publication data.

Tsay [5] explores the characteristics of the literature on hydrogen energy from 1965 to 2005 using the Science Citation Index Expanded. The results showed the hydrogen energy literature to have grown exponentially in the last decade considered, with an annual growth rate of around 18%. The countries at the forefront of production on the subject were the USA, Japan, and China with 25.8%, 14.9%, and 7.7% of the total, respectively.

Kajikawa [1] perform a network analysis of the citations of scientific publications on renewable energy to shed light on the current structure of research in this domain. The results confirmed that the fastest growing areas in research in this field are those related to fuel cells and solar cells.

Kajikawa [6] analyze the sub-areas of biomass and biofuels which have attracted increasing interest as forms of sustainable energy. They perform a network analysis of the citations of scientific papers, using clustering techniques. The results showed that, in research on biomass and biofuels, the fastest growing areas are hydrogen and biofuel production.

Finally, Celiktas [7] consider the trends of research in renewable energy over a long period (1980–2008), but focusing only on Turkey. They found publications on biomass and conversion systems, as well as on solar energy systems, to predominate. They also noted the rapid growth of the numbers of publications and citations over the last decade of their study, with more than half of all the papers having been published in the last four years.

In the present work, we shall analyze scientometrically the scientific production of the interdisciplinary field of "Renewable Energy, Sustainability and the Environment" in the Scopus database, considering the European geographical domain, and the period 2002–2007. The aim is to facilitate understanding of the evolution of emerging trends in renewable energy in that domain.

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2. Material and methods

It is well known that not all publications have the same value to scientists. While it is difficult to mark a clear distinction between publications that are of a certain level and those that are not, the broad consensus is to consider those to be found in the major bibliographic databases (principally, the Web of Science and Scopus) as the publications that are important in each subject area.

In November 2004 [9,10], the largest multidisciplinary scientific bibliographic database on the market, Scopus, was made available with more than 17,000 journals. Despite its short time in the market, this product has already been the object of several studies addressing its characterization and analysis [11–13].

In the present work, to delimit the field of renewable energy, we first selected all those documents published in journals included in the subject area of "Renewable Energy, Sustainability and the Environment" in Scopus. This first group we denominated "Articles on Renewable Energy". We then selected those documents in the database not in this first group but which met the following criteria [14,15].

(a) At least 10% of the document's references were published in journals of the Renewable Energy subject area.
(b) The journal in which the document was published has at least 2% of its articles meeting criterion (a).

We denominated this second group "Additional Items". We focused mainly on those countries with a primary production (Ndocc) of at least 50 documents. The document types considered were: articles, reviews, and conference papers.

The **SJR** (Scimago Journal Rank) is an index developed by the SCImago research group[1] to represent the visibility of the journals contained in Scopus since 1996 [16,17]. It is based on the dissemination of prestige or influence from journal to journal through references. It is size-independent, and weights the citations received by the journals within a three-year window with the prestige of the citing journal.

In particular, in calculating the **average citations per document** we applied the window as follows: for articles published in 2002, citations were counted in the period 2002–2004; for articles published in 2003, citations were counted for the period 2003–2005, etc. For the last two years considered at the time of data retrieval, 2006 and 2007, production was available only until 2007, so that two- and one-year windows were used, respectively.

The **Normalized Citation** variable was calculated as the ratio of the average citations per document for each country and the global average citations per document.

The **Percentage Variation** (PV) for the study period (2002–2007) is the percentage difference of the production (number of documents) in 2007 relative to the production in 2002.

The **Subject Specialization Index** (SSI) reflects the relative activity [18] in a particular subject area determined through the level of specialization, understood as the relative effort that a community or agent devotes to a discipline or subject area. It is quantified in relative terms as the number of documents produced in a particular discipline by a given group with respect to another group. The SSI of subject area *C* for group *E* with respect to group *M* is calculated as:

$$SSI_{CE/M} = \frac{\frac{Ndocc_{CE}}{Ndocc_E}}{\frac{Ndocc_{CM}}{Ndocc_M}} = \frac{\%Ndocc_{CE}}{\%Ndocc_{CM}}$$

where

- $Ndocc_{CE}$ is the number of documents in the field *C* in the group *E* (and analogously for $Ndocc_{CM}$);
- $Ndocc_E$ is the total number of documents of group *E* (and analogously for $Ndocc_M$);

[1] http://www.scimagojr.com/SCImagoJournalRank.pdf.

Table 1
Distribution of the "Additional Items" by specific subject area.

Categories	Ndocc
Energy Engineering and Power Technology	531
Condensed Matter Physics	291
Materials Science (miscellaneous)	257
Surfaces, Coatings and Films	222
Surfaces and Interfaces	222
Fuel Technology	221
Chemical Engineering (miscellaneous)	164
Environmental Engineering	146
Management, Monitoring, Policy and Law	124
Civil and Structural Engineering	121
Energy (miscellaneous)	115
Geography, Planning and Development	105
Mechanical Engineering	100
Fluid Flow and Transfer Processes	82
Control and Systems Engineering	77
Environmental Science (miscellaneous)	76
Organic Chemistry	72
Nuclear Energy and Engineering	66
Environmental Chemistry	40
Waste Management and Disposal	34
Chemistry (miscellaneous)	32
Physical and Theoretical Chemistry	32
Ecology	30
Filtration and Separation	29
Water Science and Technology	28
Electrochemistry	27
Analytical Chemistry	24
Electrical and Electronic Engineering	24
Geotechnical Engineering and Engineering Geology	24
Building and Construction	21
Development	19
Food Science	11
Atomic and Molecular Physics, and Optics	11
Ecology, Evolution, Behavior and Systematics	10
Electronic, Optical and Magnetic Materials	10
Physics and Astronomy (miscellaneous)	10
Engineering (miscellaneous)	8
Business, Management and Accounting (miscellaneous)	8
Multidisciplinary	8
Atmospheric Science	7
Plant Science	7
Architecture	6
Safety Research	5
Forestry	5
Safety, Risk, Reliability and Quality	5
Finance	5
Computational Mechanics	4
Mechanics of Materials	4
Process Chemistry and Technology	4
Pollution	4
Agronomy and Crop Science	4
Nature and Landscape Conservation	4
Industrial and Manufacturing Engineering	4
Statistical and Nonlinear Physics	3
Economics and Econometrics	3
Economic Geology	2
Global and Planetary Change	2
Management of Technology and Innovation	2
Modeling and Simulation	1
Organizational Behavior and Human Resource Management	1
Geophysics	1
Public Health, Environmental and Occupational Health	1
Computer Science Applications	1
Computational Theory and Mathematics	1
Computational Mathematics	1
Strategy and Management	1
Space and Planetary Science	1
Education	1

- $\%Ndocc_{CE}$ is the percentage of documents of group *E* in the field *C* relative to the total of that group's primary documents (and analogously for $\%Ndocc_{CM}$).

We also used two other indicators: **production per capita** and **production relative to Gross Domestic Product** (GDP). Population data for European countries was taken from the Eurostat website[2] and the United Nations databases (Undata)[3], and GDP data from the World Bank[4] and Undata.

3. Results and discussion

There were 8237 documents corresponding to the first group ("Articles on Renewable Energy") and 2086 documents corresponding to the second group ("Additional Items"), the total thus being 10,323. Table 1 gives the subject area distribution of the second group of documents.

One observes in Table 1 that the specific subject areas with most documents in the second group were Energy Engineering and Power Technology (531) and Condensed Matter Physics (291). Considering categories with at least 20 documents, one observes that many have some relation to Chemistry, Engineering, Materials Science, Energy, and Environmental Science.

As can be seen in Fig. 1, total European production increased considerably over the study period, doubling in those five years. The marked increase in 2006 may have been due to the entry into force in 2005 of the United Nations Framework Convention on Climate Change[5]. Both European and global primary production grew by over 100% from 2002 to 2007. At the beginning of the period, European production represented 40.38% of global production, and was down by about three percentage points at the end of the period.

As one observes in Table 2, the sum of the production of the first six countries accounts for 65% of total European production (and 25% of global production).

Comparing the production data obtained in the present study with those reported in an earlier work on the subject [3], one sees that two countries remain among those with the greatest production on Renewable Energy – the UK and Germany. The difference is in their position, since in our study the country with greatest production is the UK and in the earlier work it was Germany.

In terms of PV (the Percentage Variation) for the more productive countries, Turkey presents the greatest relative growth from 2002 to 2007 (304.17%), a characteristic that was highlighted by Celiktas [7]. In contrast, Germany, which is ranked third in terms of production, is the country with the lowest PV (4.52%) because it maintained a high but constant number of publications throughout the period.

Total European production in this subject area increased by an average of 15.59% annually, an increase similar to the global rate of increase (17.2%) over the same period. The annual increase peaked in 2006 at around 34% both in Europe and globally.

The countries making the greatest effort in renewable energy relative to global production were Turkey with an SSI of 4.52, and Greece with an SSI of 3.31. This means that the percentage of their total production of documents on renewable energy relative to their total production is greater by those factors than the equivalent percentage worldwide. There follow in order Lithuania, Slovenia, Sweden, and Denmark.

It should be noted that the SSI of Europe relative to the World in this field is 0.89. Considering the values representing this effort corresponding to the top third of European countries in terms of production (UK, Turkey, Germany, Italy, Sweden, Spain, and France), one sees that, with the exceptions of Turkey (which stands far above the rest), Sweden, and Spain, the other four are below the European average, with France having the lowest SSI (0.54).

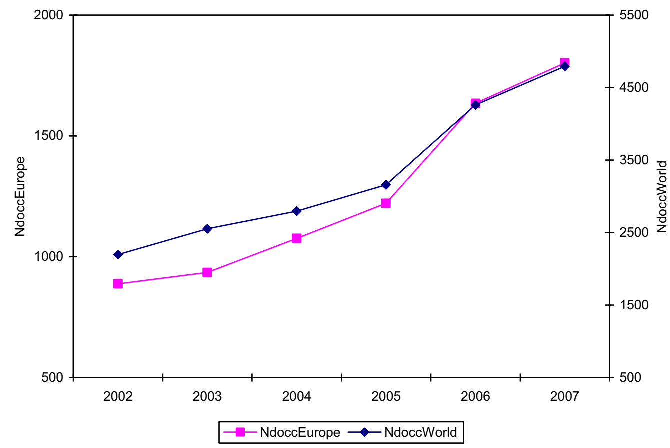

Fig. 1. Temporal evolution of primary production in Europe and globally (2002–2007).

Fig. 2 shows each country's percentages of production together with its SSI. One notes that, among those with greatest production, Turkey and Greece have the highest SSI values.

Fig. 3 shows how the Nordic countries Sweden and Denmark had the most articles per capita, with 66.61 and 56.18 per million inhabitants, respectively. They were followed by Greece, Slovenia, Switzerland, and Finland, these last with values of around 40. The lowest values, 3.11 and 0.60, corresponded to Romania and Russia, respectively.

With respect to number of articles relative to GDP for the period 2002–2007, Slovenia, Turkey, Greece, Lithuania, and Sweden ranked top with values above 1.3 articles per billion US$. The case of France stands out as being ranked fairly high (seventh) in terms of production, but with low values of SSI and of the indicators relative to population size and GDP.

One observes that there is a group of countries – Sweden, Slovenia, and Greece – which rank at the top in number of articles per capita and relative to GDP, all well above the European average and the global values.

As one observes in Table 3, the countries with the greatest values (all above 1.7) of Total Normalized Citation were Switzerland, Denmark, Sweden, and the Netherlands. The value for Europe as a whole was 1.37, which was also surpassed by Germany, Turkey, Belgium, and Austria, while Norway equaled this average value.

At the other extreme were Russia, Portugal, Slovenia, and Poland, none of which reached 0.9, their values being between 35% and 45% below the value obtained by Europe as a whole.

Ignoring Russia and Lithuania which have a very low annual production of documents, the countries with the greatest mean annual growth in this indicator (far above the European average) are Austria, Norway, Denmark, and the Netherlands. Austria, in particular, underwent major growth in terms of the Normalized Citation.

Comparing scientific production on renewable energy with the Normalized Citation values, one sees that Turkey and Germany, which are ranked second and third respectively in terms of scientific output, are also ranked high in terms of citations received (6th and 5th, respectively). On the contrary, the UK drops from the top in production to the middle of the list in terms of Total Normalized Citation.

2 http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ (2009-05-04).
3 http://unstats.un.org/unsd/cdb_discontinued/cdb_discontinued.asp (2009-10-05).
4 http://www.pdwb.de/archiv/weltbank/gdp07.pdf (2009-05-04).
5 http://archivo.greenpeace.org/Clima/Prokioto.htm.

Table 2
Temporal evolution by country of production, SSI, and PV (2002–2007).

Country	2002	2003	2004	2005	2006	2007	Ndocc	PV	SSI
United Kingdom	133	136	177	174	224	299	1143	124.81	0.84
Turkey	72	123	165	180	265	291	1096	304.17	4.52
Germany	155	128	126	129	177	162	877	4.52	0.68
Italy	66	91	88	89	125	152	611	130.30	0.85
Sweden	65	73	104	111	137	117	607	80.00	2.17
Spain	56	58	78	120	144	128	584	128.57	1.08
France	75	66	60	77	102	115	495	53.33	0.54
Greece	43	62	53	59	116	126	459	193.02	3.31
Netherlands	65	58	54	87	99	93	456	43.08	1.14
Denmark	36	36	45	42	67	80	306	122.22	2.07
Switzerland	31	35	48	71	54	63	302	103.23	1.05
Belgium	31	31	27	31	49	58	227	87.10	1.03
Finland	27	25	35	27	44	54	212	100.00	1.45
Poland	24	23	20	28	36	33	164	37.50	0.60
Portugal	12	11	17	24	37	37	138	208.33	1.45
Norway	17	14	18	25	20	40	134	135.29	1.22
Austria	5	16	24	18	34	36	133	620.00	0.86
Ireland	4	6	19	18	28	29	104	625.00	1.42
Russian Federation	13	11	10	16	16	18	84	38.46	0.18
Slovenia	9	7	6	11	21	28	82	211.11	2.20
Romania	12	14	4	11	12	14	67	16.67	1.30
Lithuania	1	3	8	6	14	22	54	2100.00	2.84
Europe	888	935	1076	1221	1635	1802	7557	102.93	0.89
World	2199	2552	2797	3158	4260	4795	19,761	118.05	

With respect to the SJR, this indicator varied less between countries than the Normalized Citation – its coefficient of variation was 9.73% compared with 29.31% for the Total Normalized Citation. The mean SJR for the principal European countries was around 0.070. The countries with the highest SJR values, and which therefore are making the greatest efforts in disseminating their results, are Germany, followed by Slovenia and Lithuania (although these have very few documents), Spain, Switzerland, and Belgium, all with values between 7% and 18% above the European average. Those with the lowest SJR values are Turkey, Russia, UK, Romania, and Greece, with values between 11% and 22% below the European average.

Application of a hierarchical clustering algorithm using average linkage between groups to the normalized variables Ndocc, PV, Normalized Citation, and SJR revealed 5 clusters for which the differences were highly significant (sig. < 0.01) in the indicators Ndocc, SSI, Total Normalized Citation, and significant ($0.01 <$ sig. < 0.05) in PV and SJR. Fig. 4 shows the dendrogram resulting from this procedure.

These five clusters of countries can be described according to the average values of the variables used in the analysis:

- Cluster 1 comprises only Turkey and Greece. We would label them as emergent in the present context. They have high values of production, PV, and SSI, and values close to the European average in Normalized Citation (slightly above), and SJR (slightly below). These countries do not have a high GDP, but are making a major budgetary effort in this field.
- Cluster 2 comprises Romania, Norway, Finland, Portugal, Russia, and Poland. These are countries which could be labeled as close

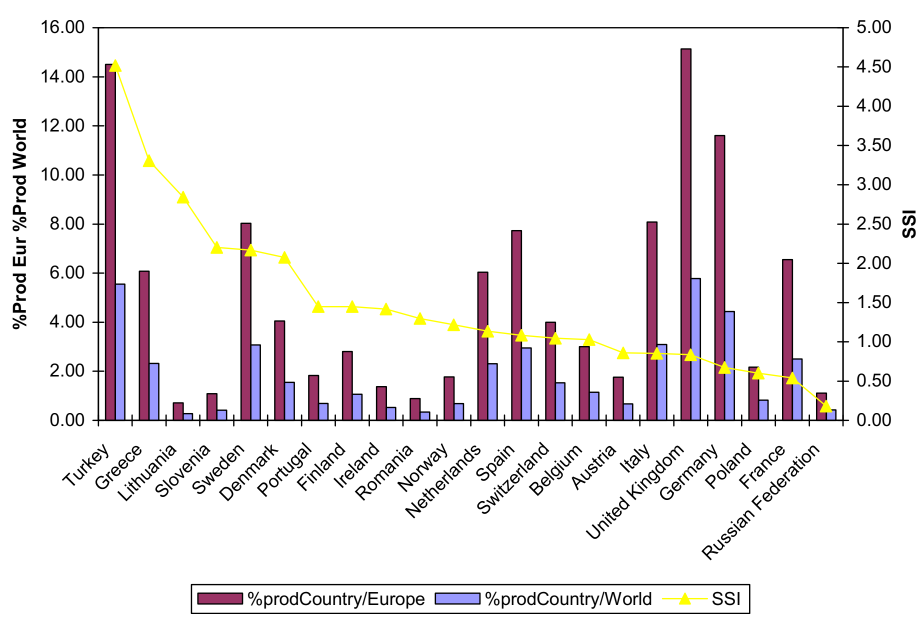

Fig. 2. Percentage of production in each country relative to European and global production, and the Subject Specialization Index.

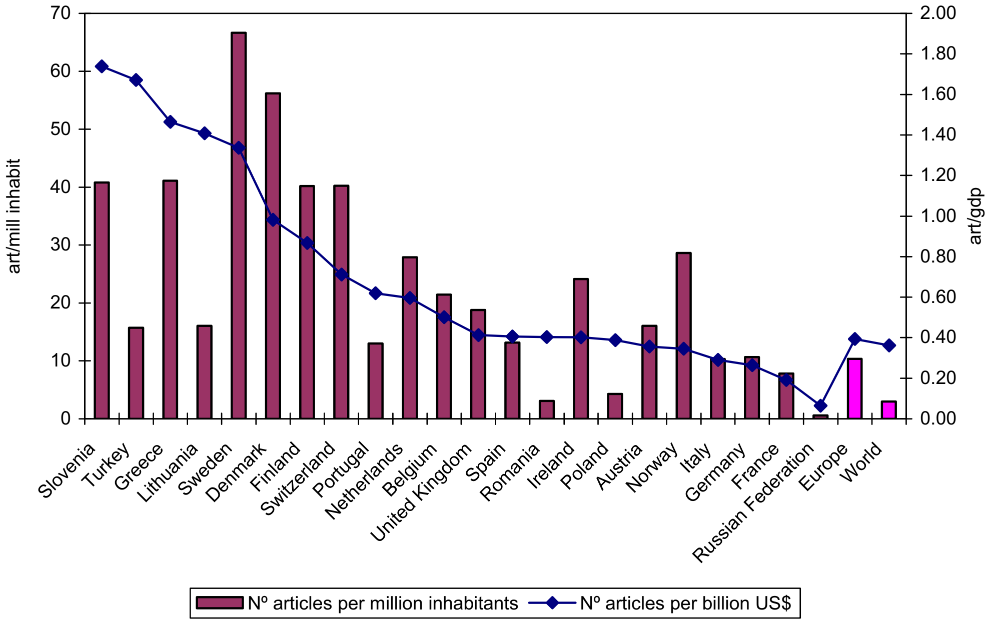

Fig. 3. Number of articles per million inhabitants and relative to the GDP of the principal countries of Europe.

to the average in the present context. They are characterized by low production but high PV, and close to the global average in SSI, Normalized Citation, and SJR.

- Cluster 3 comprises UK, Italy, Spain, Germany, and France. They could be labeled as advanced countries in this context, since they have high values of production and Normalized Citation, low values of PV and SSI, and a slightly above average SJR. They have high GDPs, and a major, but stable volume of quality research in the sector, reflecting more the sheer size of the country than any particular specialization or effort.
- Cluster 4 comprises Ireland, Lithuania, Austria, and Slovenia. We would label this group as being initiates, characterized by a low average production but high PV and SSI, and values slightly above the global average in Normalized Citation and SJR.
- Cluster 5 comprises Belgium, Switzerland, Denmark, the Netherlands, and Sweden. We would label them as specialists, since they present an average production and SJR, and a low PV, but high values of SSI and Normalized Citation. Their production is high compared to their GDP, and especially compared to their population size.

In Table 4, one observes that the journal "Solar Energy Materials and Solar Cells" is that with the greatest number of documents, followed by "Energy Conversion and Management". These

Table 3
Primary production, average citations per document, Normalized Citation (using a three-year window except for the last two years in both of these last two cases), Total Normalized Citation, and average SJR of the principal European countries.

Countries	Total Ndocc	Average (citation/doct)						Standard citation						Total Standard citation	SJR
		2002	2003	2004	2005	2006	2007	2002	2003	2004	2005	2006	2007		
Switzerland	302	2.71	5.43	3.46	3.99	2.11	0.49	1.74	2.69	1.63	1.66	2.11	2.21	2.07	0.076
Denmark	306	2.28	2.17	5.16	5.29	3.01	0.59	1.47	1.07	2.43	2.20	3.02	2.64	2.03	0.067
Sweden	607	3.72	3.59	3.01	4.03	1.50	0.38	2.40	1.78	1.42	1.68	1.50	1.69	1.80	0.073
Netherlands	456	2.54	3.81	2.52	4.09	1.80	0.59	1.63	1.89	1.19	1.70	1.80	2.65	1.76	0.068
Germany	877	2.24	3.23	3.88	3.52	1.58	0.47	1.44	1.60	1.83	1.46	1.58	2.10	1.69	0.083
Turkey	1096	3.83	3.59	3.88	4.02	1.12	0.36	2.47	1.78	1.83	1.67	1.12	1.62	1.63	0.057
Belgium	227	2.74	2.84	4.07	3.16	2.08	0.41	1.77	1.41	1.92	1.32	2.08	1.86	1.61	0.075
Austria	133	0.80	3.88	3.04	3.89	0.85	1.06	0.51	1.92	1.43	1.62	0.85	4.73	1.50	0.073
Norway	134	1.53	1.57	3.28	4.28	1.00	0.50	0.98	0.78	1.55	1.78	1.00	2.24	1.37	0.066
Spain	584	2.07	2.10	2.31	3.18	1.26	0.45	1.33	1.04	1.09	1.32	1.26	2.03	1.28	0.078
United Kingdom	1143	1.68	2.65	2.27	2.87	1.68	0.35	1.08	1.31	1.07	1.20	1.68	1.56	1.24	0.063
Romania	67	2.42	2.07	3.75	2.09	1.25	0.14	1.56	1.03	1.77	0.87	1.25	0.64	1.22	0.063
Greece	459	2.07	2.26	2.68	3.19	1.22	0.24	1.33	1.12	1.26	1.33	1.22	1.07	1.15	0.063
Italy	611	1.91	1.95	2.48	2.61	1.14	0.39	1.23	0.96	1.17	1.08	1.14	1.77	1.13	0.067
France	495	1.97	2.30	2.33	2.27	0.90	0.43	1.27	1.14	1.10	0.95	0.90	1.95	1.10	0.072
Lithuania	54		0.67	2.00	6.00	1.21	0.32		0.33	0.94	2.50	1.22	1.43	1.04	0.078
Ireland	104	2.50	1.00	2.58	1.89	1.57	0.21	1.61	0.50	1.22	0.79	1.57	0.93	1.03	0.066
Finland	212	1.70	1.68	2.03	2.78	1.16	0.31	1.10	0.83	0.96	1.16	1.16	1.41	1.03	0.067
Poland	164	0.96	1.83	1.30	2.75	0.75	0.24	0.62	0.91	0.61	1.14	0.75	1.09	0.89	0.069
Slovenia	82	1.33	1.57	1.67	3.18	0.86	0.25	0.86	0.78	0.79	1.32	0.86	1.12	0.82	0.082
Portugal	138	1.83	1.45	2.65	1.58	0.70	0.14	1.18	0.72	1.25	0.66	0.70	0.61	0.79	0.070
Russian Federation	84	0.54	2.36	1.00	1.56	0.69	0.44	0.35	1.17	0.47	0.65	0.69	1.99	0.75	0.059
Europe	7557	2.14	2.75	2.92	3.20	1.35	0.35	1.38	1.36	1.38	1.33	1.35	1.56	1.37	
World	19,761	1.55	2.02	2.12	2.40	1.00	0.22								

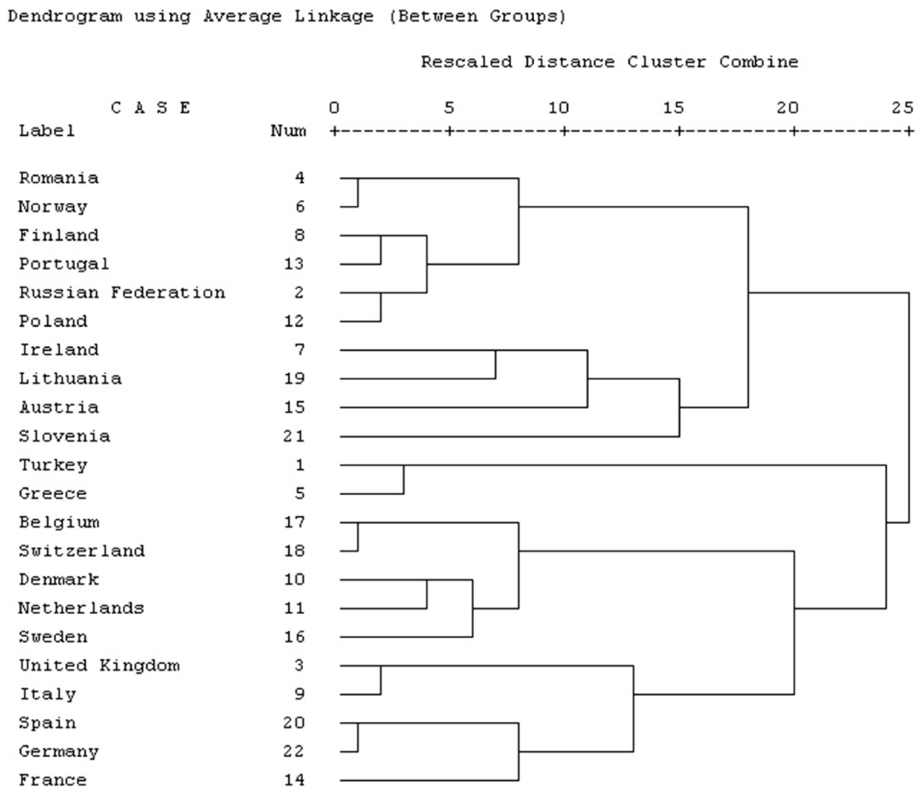

Fig. 4. Dendrogram of the principal countries as obtained by the hierarchical clustering procedure.

also received the greatest number of citations. But relating them with the number of documents or the Normalized Citation led to the former falling to fifth position, and the latter falling 13 positions. With this criterion, they were overtaken by journals with very few documents – "Progress in Photovoltaics: Research and Applications", "Annual Review of Environment and Resources", "Fuel", and "Thin Solid Films". Except for the review journal, and unlike the two first mentioned journals, these belong to specific subject areas other than 'Renewable Energy, Sustainability and the Environment'.

Several of the publications in the table are directly related to two of the outstanding topics in renewable energy research that have been identified in earlier work – biomass and solar energy [1,6,7]. Uzun [3] also highlights the field of photovoltaic technology as being the most productive.

The journal with the highest mean annual growth rate in Normalized Citation was "Environmental Science and Policy". Its growth in the last year (2007) studied was particularly notable. At a certain distance follow "Wind Energy", "Environmental Impact Assessment Review", "Environmental Research Letters", "Annual Review of Environment and Resources", "Renewable and Sustainable Energy Reviews", "Energy Sources, Part B: Economics, Planning and Policy", and "Renewable Energy", all journals within the renewable energy subject area.

The SJR index showed less variation among the different journals than the citations (although in both cases, the variation was high). The mean SJR was 0.07, with only 27% of the journals surpassing this value. The Total Normalized Citation of the set of journals analyzed and their SJR values presented a certain correlation (Pearson's R coefficient equal to 0.79). Indeed, the top five ranked journals according to the Total Normalized Citation remained essentially the same in the ranking according to the SJR, the exception being "Fuel" which dropped 8 positions to be replaced by a journal from another area: "International Journal of Hydrogen Energy".

The medians of the number of documents, the Normalized Citation, and the SJR were less than the corresponding means, reflecting a skew of the distributions to the right. This was especially so for the cases of number of articles per year and the SJR, while the differences for the Total Normalized Citation were very small.

The clustering procedure was then applied to the 45 journals for which all the data were available. The analysis was limited to 3 clusters which presented highly significant differences in all the variables (sig. < 0.01). Fig. 5 shows the dendrogram resulting from this analysis.

These three clusters of journals can be described according to the average values of the variables used in the analysis:

- Cluster 1 in the last part of the dendrogram is characterized by a small mean number of documents per journal, and the greatest values of Normalized Citation and SJR. Of the 15 journals in the group, 9 belong to other specific subject areas, and one of the other 6 also has other ascriptions as well as the Renewable Energy subject area.
- Cluster 2 in the first part of the dendrogram also has a small mean number of documents per journal, but this time with very low values of the Normalized Citation and SJR. Of the 20 journals in this group, 8 belong to other areas, and 9 of the other 12 also have ascriptions to various areas.
- Cluster 3 corresponds to the 10 journals in the center of the dendrogram. They have an intermediate impact as measured by the Normalized Citation and SJR (the latter somewhat above the average value), and a large number of documents per journal. All 10 journals are ascribed to the subject area in question, while 5 of them have other ascriptions too.

Table 4

Primary production, average citations per document, Normalized Citation (using a three-year window except for the last two years in both of these last two cases), Total Normalized Citation, and average SJR of the journals that published most studies included in the present study.

Journal	Ndocc						TOTAL PPrim	Average (citation/doct)						Standard citation						Total Std. Cit.	SJR
	2002	2003	2004	2005	2006	2007		2002	2003	2004	2005	2006	2007	2002	2003	2004	2005	2006	2007		
Progress in Photovoltaics: Research and Applications	11	17	7	13	21	16	85	3.45	14.35	5.71	2.62	1.48	0.44	2.22	7.12	2.69	1.09	1.48	1.96	3.34	0.169
Annual Review of Environment and Resources		18	11	13	14	15	71		5.33	4.73	10.77	2.50	0.20		2.64	2.23	4.48	2.5	0.9	3.31	0.244
Fuel	4	5	9	16	24	27	85	5.50	3.00	7.00	7.31	2.42	0.63	3.54	1.49	3.3	3.04	2.42	2.82	2.48	0.082
Thin Solid Films	29	44	39	56	68	70	306	4.97	4.93	5.05	4.86	2.40	0.31	3.2	2.45	2.38	2.02	2.4	1.41	2.39	0.131
Solar Energy Materials and Solar Cells	228	298	163	238	344	269	1540	2.82	4.08	5.96	4.50	2.44	0.49	1.82	2.02	2.81	1.87	2.45	2.2	2.28	0.138
Renewable and Sustainable Energy Reviews	20	25	30	35	27	118	255	5.80	2.32	3.53	6.49	4.48	1.01	3.73	1.15	1.67	2.7	4.48	4.52	2.11	0.092
Biomass and Bioenergy	97	92	110	86	122	88	595	2.88	2.78	3.58	5.05	1.52	0.27	1.85	1.38	1.69	2.1	1.53	1.22	1.91	0.088
Fuel Processing Technology	1	5	3	12	21	13	55	5.00	2.60	5.00	3.92	2.43		3.22	1.29	2.36	1.63	2.43		1.72	0.080
Environmental Science and Policy	39	49	42	63	62	59	314	1.95	2.29	3.31	2.90	1.90	1.49	1.25	1.13	1.56	1.21	1.9	6.69	1.64	0.067
Applied Energy	13	8	29	25	28	33	136	1.69	2.25	4.14	3.12	1.43	0.33	1.09	1.12	1.95	1.3	1.43	1.5	1.53	0.055
Wind Energy		26	26	31	37	34	154		2.15	2.31	4.29	1.38	0.71		1.07	1.09	1.79	1.38	3.17	1.52	0.043
Energy Policy	8	6	10	17	37	77	155	3.38	3.50	3.00	5.82	2.89	0.52	2.17	1.74	1.41	2.42	2.89	2.33	1.51	0.061
Solar Energy	90	97	176	150	173	149	835	1.70	1.91	2.99	4.09	1.31	0.22	1.09	0.95	1.41	1.7	1.31	0.99	1.50	0.085
Energy and Fuels	7	5	5	15	21	35	88	2.71	2.20	5.40	5.13	2.24	0.06	1.75	1.09	2.55	2.14	2.24	0.26	1.50	0.096
Energy Conversion and Management	207	216	211	206	283	329	1452	1.84	3.07	3.57	3.51	1.45	0.26	1.18	1.52	1.68	1.46	1.45	1.19	1.50	0.066
Environmental Impact Assessment Review	35	32	44	44	42	41	238	1.57	2.78	2.95	3.50	1.05	0.46	1.01	1.38	1.39	1.46	1.05	2.08	1.49	0.053
Energy Sources	14	20	46	22			102	2.93	1.15	2.22	1.05			1.89	0.57	1.05	0.44			1.34	
Renewable Energy	136	170	160	156	184	179	985	1.53	2.22	2.14	3.25	1.45	0.39	0.98	1.1	1.01	1.35	1.45	1.73	1.30	0.058
International Journal of Hydrogen Energy	4	5	5	3	17	30	64	6.00	1.40	5.20	4.67	2.18	0.10	3.86	0.69	2.45	1.94	2.18	0.45	1.25	0.131
Resources, Conservation and Recycling	60	62	66	65	76	119	448	1.90	2.45	2.48	3.55	1.12	0.19	1.22	1.22	1.17	1.48	1.12	0.87	1.24	0.059
Journal of Cleaner Production	56	84	97	127	171	165	700	1.96	2.55	2.23	3.35	0.98	0.38	1.26	1.26	1.05	1.39	0.98	1.71	1.23	0.052
Energy	72	95	182	184	233	235	1001	1.54	2.06	2.28	3.04	1.44	0.28	0.99	1.02	1.08	1.27	1.44	1.24	1.21	0.060
Applied Thermal Engineering	18	25	29	39	66	68	245	2.61	3.52	2.31	2.90	1.09	0.24	1.68	1.75	1.09	1.21	1.09	1.06	1.19	0.058
Energy and Buildings	107	110	134	130	161	137	779	2.38	1.84	1.91	2.39	1.14	0.12	1.53	0.91	0.9	1	1.14	0.52	1.13	0.058
Building and Environment	15	18	22	28	45	78	206	1.13	2.06	2.27	3.25	1.67	0.29	0.73	1.02	1.07	1.35	1.67	1.32	1.03	0.053
Journal of Solar Energy Engineering, Transactions of the ASME	20	10	12	13	32	21	108	2.00	2.60	1.25	1.92	0.84	0.43	1.29	1.29	0.59	0.8	0.84	1.92	0.95	0.055
Journal of Wind Engineering and Industrial Aerodynamics	134	117	62	49	50	90	502	1.31	1.42	1.63	2.39	1.18	0.07	0.85	0.7	0.77	0.99	1.18	0.3	0.90	0.052
International Journal of Photoenergy	24	35	30	29	40	25	183	1.42	1.80	1.70	2.21	0.33	0.04	0.91	0.89	0.8	0.92	0.33	0.18	0.89	0.063
Desalination	4	10	13	25	8	39	99	1.00	2.10	1.92	2.04	0.75	0.18	0.64	1.04	0.91	0.85	0.75	0.81	0.83	0.067
International Journal of Energy Research	15	10	20	18	37	30	130	2.33	1.20	1.70	1.94	0.62	0.13	1.5	0.59	0.8	0.81	0.62	0.6	0.79	0.053
Journal of Energy Resources Technology, Transactions of the ASME	37	39	41	38	41	31	227	1.05	1.10	1.17	1.42	0.54	0.16	0.68	0.55	0.55	0.59	0.54	0.72	0.67	0.045
Wind and Structures, An International Journal	39	29	29	29	31	31	188	1.03	0.83	1.38	1.17	0.48	0.19	0.66	0.41	0.65	0.49	0.48	0.87	0.61	0.044
ASHRAE Transactions	6	4	11	14	13	8	56	1.17	1.75	0.91	0.93	0.77		0.75	0.87	0.43	0.39	0.77		0.61	0.042
Energy and Environment	48	34	54	46	42	46	270	0.23	1.91	0.85	0.89	0.45	0.11	0.15	0.95	0.4	0.37	0.45	0.49	0.50	0.045
International Journal of Ambient Energy	6	10	11	14	8	10	59	0.17	1.10	0.18	1.07		0.10	0.11	0.55	0.09	0.45		0.45	0.37	0.040
Huagong Xuebao/Journal of Chemical Industry and Engineering (China)	3	4	7	5	22	13	54		0.50	1.29	0.40	0.59			0.25	0.61	0.17	0.59		0.35	0.041
Conference Record of the IEEE Photovoltaic Specialists Conference	80			93			173	0.40			0.31			0.26			0.13			0.25	
Energy Sources, Part B: Economics, Planning and Policy					37	36	73					0.41	0.17					0.41	0.75	0.21	0.016
Environmental Research Letters					12	49	61					0.58	0.20					0.58	0.92	0.20	0.127
International Journal of Sustainable Energy		18		18	14	16	66		0.17		0.78				0.08		0.32			0.19	0.039
Energy Sources, Part A: Recovery, Utilization and Environmental Effects					131	139	270					0.37	0.09					0.37	0.39	0.16	0.017
International Journal of Green Energy					30	40	70					0.33	0.10					0.33	0.45	0.14	0.018
Refocus	40	36	44	32	6		158	0.05	0.08	0.14	0.38			0.03	0.04	0.06	0.16			0.10	
Gong Cheng Li Xue/Engineering Mechanics	1	3	6	7	15	18	50			0.17	0.43	0.07	0.06			0.08	0.18	0.07	0.25	0.09	0.037
Taiyangneng Xuebao/Acta Energiae Solaris Sinica	21	26	34	33	71	65	250	0.19	0.12	0.21	0.09	0.04		0.12	0.06	0.1	0.04	0.04		0.06	0.036
International Journal of Sustainable Development and Planning					32	29	61					0.09						0.09		0.04	0.015
International Solar Energy Conference	47	93	84	101	213	82	620	0.23	0.09	0.02	0.03			0.15	0.04	0.01	0.01			0.03	0.035
Research Journal of Chemistry and Environment						66	66						0.03						0.14	0.02	
Asia-Pacific Journal of Chemical Engineering					12	80	92					0.08	0.01					0.08	0.06	0.02	0.034
Thermal Science						53	53						0.02						0.08	0.01	
Applied Solar Energy (English translation of Geliotekhnika)	24	8	72	51	48	51	254														0.028
Europe	888	935	1076	1221	1635	1802	7557	2.14	2.75	2.92	3.20	1.35	0.35	1.38	1.36	1.38	1.33	1.35	1.56	1.37	
World	2199	2552	2797	3158	4260	4795	19,761	1.55	2.02	2.12	2.40	1.00	0.22								

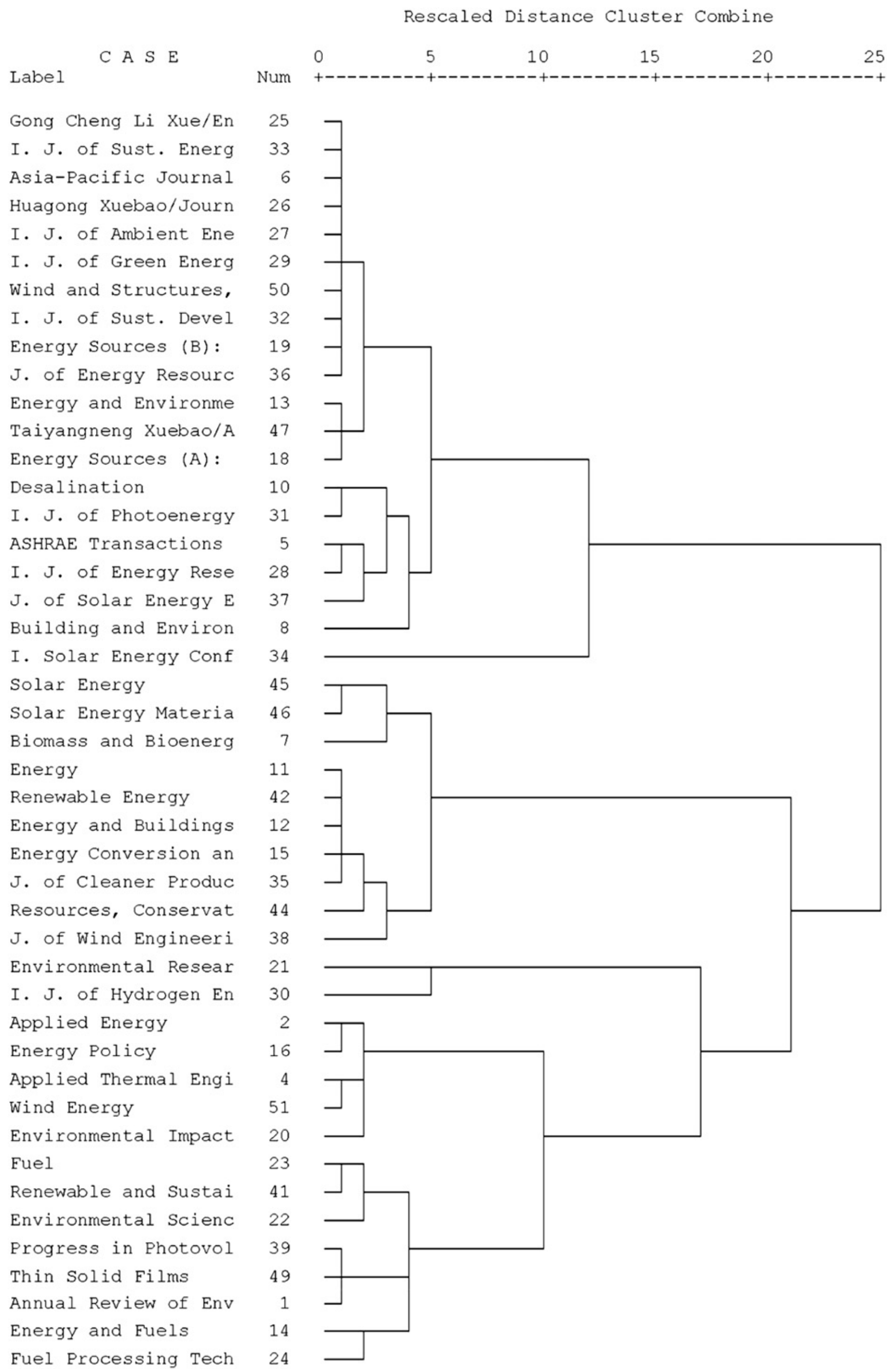

Fig. 5. Dendrogram of the principal journals as obtained by the hierarchical clustering procedure.

4. Conclusions

Global scientific production in the renewable energy field has been growing at an ever-faster rate as befits the need in today's world for new knowledge with which to tackle the problems of energy sustainability. But this growth has been uneven across the different domains of science, and has very different characteristics in different subfields. The thematic (journals) and geographical (countries) structure revealed by the clustering procedures used in the present work can advance our understanding of scientific developments in this emerging field which, unlike more traditional fields, allows countries that are not among the most powerful scientifically to occupy quite prominent positions on a world scale. Indeed, renewable energy is a field in which one can appreciate dynamics of scientific development that are very different from those prevailing in the world of science in general. This is especially noticeable in certain developing countries which are making significant efforts to reduce their energy dependency on less sustainable sources. The study reveals that in the period 2002–2007:

- A far from negligible number of works related to renewable energies were published in journals not ascribed to the "Renewable Energy, Sustainability and the Environment" specific subject area.

- Global and European production doubled over the period. Europe, which accounts for 40% of global production, is growing at a slower pace than the rest of the world. There was a marked increase in production in 2006 which may have been the result of the entry into force in 2005 of the Kyoto protocol.
- Relative to GDP and particularly to population, Europe is putting greater effort into research in this field than the world as a whole. This is not so, however, relative to the total of its research production as indicated by the SSI. For this, one has to bear in mind that the world total also includes developing nations.
- The impact of Europe in this area, as measured by the Normalized Citation, is above the global value, and grew by more than 10% in the period.

The countries of Europe can be clustered into five groups with respect to their research in this field:

- Advanced countries, which are powers in terms of their scientific production in general. They have a high production which is also of high impact, but which has clearly stabilized. The magnitude of their production reflects the overall volume of their scientific output rather than any particular specialization.
- Specialist countries, mainly Nordic nations. They have a substantial high quality output, reflecting their traditional efforts in this field rather than any overall volume of scientific production.
- Emergent countries, consisting of Greece and Turkey. They have a production of average quality but of considerable size and growing. This size rather reflects effort and specialization in the field than any general capacity of these countries.
- Initiate countries, consisting of nations with a small production of impact close to the global average, but with a fairly major specialization and growing production.
- Intermediate countries, with a low but growing production, and impact and specialization similar to those of the world as a whole.

Finally, the journals used form three groups:

- The first consists of journals with a small mean number of documents, but of the greatest impact. They are primarily ascribed to other subject areas.
- The second consists of journals also with a small mean number of documents, but now of low impact. Many are ascribed to other subject areas, but also many belong to the area in question.
- And the third consists of more specialized journals in the area with a large mean number of documents, and an intermediate impact somewhat above the average.

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