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World scientific production on renewable energy, sustainability and the environment

Luz M. Romo-Fernández [a], Vicente P. Guerrero-Bote [a,*], Félix Moya-Anegón [b]

[a] University of Extremadura, Department of Information and Communication, SCImago Group, Spain
[b] CSIC, CCHS, IPP, SCImago Group, Spain

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ABSTRACT

This study examines world scientific production on renewable energy, sustainability and the environment on the basis of bibliometric indicators (scientific production, percentage variation of production, average cites per document, normalized impact, impact, etc.) for the period 2003–08. The analysis is made by country, by research institution, and by scientific journal, using the Scopus (Elsevier) database of scientific literature. The results show the total world production to have increased during the period studied, and that this topic has been attracting great scientific interest. Two groups of countries with high production are distinguished, one of which has a highly specialized subject focus. There are also three groups of institutions with a major production, two of which also have high impact.

Introduction

The focus of the present work is Renewable Energy, Sustainability and the Environment, a topic of major interest in that it is an important component of sustainable development. There have been only a few bibliometric studies on this area, however, and there is a clear need for an overview of the research (Dalpe, 2002; Garfield, 1992; Strehl and Dos Santos, 2002).

In this sense, Thomas (1992) evaluates the work of research groups in the field of biomass, considering areas outside the U.S. and the E.E.C. Uzun (2002) compares the research results and priorities of 25 countries in renewable energy for the periods 1996–97 and 1998–99, using as measures the numbers of publications and their increase, and a research priority index. Hassan (2005), 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 using patent and scientific publication data as basis. Tsay (2008) 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 that was considered, with an annual growth rate of some 18%. Kajikawa et al. (2008) 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 and Takeda (2008) 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 documents, using clustering techniques. The results show that the fastest growing areas in research on biomass and biofuels are hydrogen and biofuel production. Celiktas et al. (2009) consider the trends of research in renewable energy over a long period (1980–2008), but focusing only on Turkey. They found the predominant publications to be on biomass and conversion systems, as well as on solar energy systems. 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 documents having been published in the last four years. And finally, (Romo Fernández et al., 2011) provide an overview of the research of major European countries in the area of renewable energy for the period 2002–07, using the Scopus (Elsevier) scientific literature database. The results show global and European production to have doubled over the period studied, and that Europe, which has 40% of global production, is growing at a slower pace than the rest of the world.

Most of these scientometric studies were limited to a specific type of energy or a particular country, and did not treat the subject area as a whole. They also take restricted methodological approaches in both the data retrieval strategy and the calculation of the indicators.

In the present work, we analyze scientific production in the Renewable Energy, Sustainability and the Environment category using bibliometric indicators (production, normalized impacts, and their percentage variations, the subject specialization index, cites per document, SJR, etc.) for the period 2003–08. As independent variables, we consider countries, major research institutions, and scientific journals.

* Corresponding author at: Facultad de Biblioteconomía y Documentación, Pl/Ibn Marvan s/n, 06001 Badajoz, Spain. Tel.: +34 645440889; fax: +34 924286401.
E-mail address: guerrero@unex.es (V.P. Guerrero-Bote).

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Although these indicators are to study the quantity and quality of scientific publications, they may not represent the importance of the issues treated.

Material and methods

In November 2004, the largest multidisciplinary scientific bibliographic database on the market, Scopus, was made available with a coverage of more than 17 000 journals (Hane, 2004 and Pickering, 2004). Despite its short time on the market, this product has already been the object of several studies addressing its characterization and analysis (Archambault et al., 2009; Leydesdorff et al., 2010; Moya Anegón et al., 2007). In the present work, we use the Scimago Institutions Rankings (SIR), a Scopus-based science evaluation resource to assess universities and research-focused institutions (government agencies, research laboratories, hospitals, etc.; see Scimago Institutions Rankings, 2010 http://www.scimagoir.com/methodology.php), to study those countries and institutions with a production (Ndoc) of at least 50 documents and journals in the subject area of Renewable Energy, Sustainability and the Environment.

The SJR (Scimago Journal Rank) index was developed by the SCImago research group[1] to represent the visibility of the journals contained in Scopus since 1996 (Bollen et al., 2009; González Pereira et al., 2010). It is based on the dissemination of prestige or influence from journal to journal through references. It is size-independent, and weights the cites received every year by the journals to the papers published in the previous three years with the prestige of the citing journal.

The normalized impact scores are measures of the scientific impact that institutions have on the scientific community as a whole. In order to obtain a fair measurement of this impact, their calculation removes the influence due to the institutions' sizes and research profiles, making it ideal for comparing research performance. The normalized impact values are averages of the ratios between the citation of the papers of the institution or country and the world average citation of publications with the same time frame, document type, and subject area. A NI of 1 means that the institution or country cited equal to the world average, then a score of 0.8 means the institution or country is cited 20% below the world average and 1.3 means the institution or country is cited 30% above the world average.

The percentage variation of production (PVP) for the period studied (2003–08) is the percentage difference in the number of works in 2008 relative to the total production of 2003.

The percentage variation of the normalized impact (PVNC) for the period studied (2003–08) is the percentage difference of the normalized impact in 2008 relative to the total normalized impact of 2003.

The subject specialization index (SSI) reflects the relative activity (Moya Anegón et al., 2004) 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 A for group C with respect to group W is calculated as:

$$SSI_{AC/W} = \frac{\frac{Ndocc_{AC}}{Ndocc_{C}}}{\frac{Ndocc_{AW}}{Ndocc_{W}}} = \frac{\%Ndocc_{AC}}{\%Ndocc_{AW}}$$

where

- $Ndocc_{AC}$ is the number of documents in the field A in the group C (and analogously for $Ndocc_{AW}$);
- $Ndocc_{C}$ is the total number of documents of group C (and analogously for $Ndocc_{W}$);
- $\%Ndocc_{AC}$ is the percentage of documents of group C in the field A relative to the total of that group's primary documents (and analogously for $\%Ndocc_{AW}$).

In this paper, SSI is used to quantify the specialization of individual countries in Renewable Energy, Sustainability and the Environment with respect to the world. That is, A is Renewable Energy, Sustainability and the Environment, W is the world's research output and C is the research output of each country.

Results

We analyzed the principal countries of the world with scientific production in the field of Renewable Energy, Sustainability and the Environment, focusing primarily on those which have a production of at least 50 documents, and on the institutions and journals that are most productive in this category.

Table 1 presents the evolution of the production of countries which have at least 50 documents published in journals covered by Scopus, their total documents, their percentage variation of production, and their subject specialization index for the period 2003–08.

As one observes in the table, the U.S. is the country with the greatest production in the period, reaching a peak in 2006. It is followed by China, the U.K., India, Turkey, and Japan. The production of the U.S. is about 50% higher than the production of China. China experienced major growth between 2003 and 2008, followed by India, whereas the production of the U.S., Germany, and Japan was relatively stable (Fig. 2).

The countries which do not surpass the world average percentage variation are France, Denmark, South Korea, Malaysia, Singapore, New Zealand, Sweden, Belgium, U.S., Germany, Romania, Israel, Jordan, Japan, Mexico, Saudi Arabia, and Sri Lanka (Fig. 2).

The most productive countries that made the greatest relative effort (SSI) in renewable energy, sustainability and the environment are Turkey and Greece.

Table 2 presents the total cites received in the period studied, the cites per document, the percentage of documents cited, the evolution of the normalized impact, the total normalized impact, and the percentage variation in the normalized impact of the countries of the world.

Considering the countries with the greatest production, one observes that the highest values of cites per document correspond to Turkey, The Netherlands, Hong Kong, Taiwan, and Switzerland. With respect to the percentage of documents cited, Hong Kong is the country most often cited in relative terms, followed by Denmark, Sweden, and The Netherlands.

The countries with the highest values of the normalized impact are Denmark, The Netherlands, Switzerland, Belgium, and Germany (Fig. 1), all of which surpass the world average by more than 30%. Tunisia, Jordan, Egypt, Nigeria, Russia, and Uzbekistan are the countries with the lowest values of normalized impact for the period studied, not exceeding 70% of the world average.

Again considering the most productive countries, the greatest increase in normalized impact during the period studied corresponds to Denmark, followed by Hong Kong, Australia, and Germany (Fig. 2), while The Netherlands and Belgium, with a good normalized impact, present slight decreases.

One can establish five groups of countries according to the values of the indicators described above:

- The first group, which we label as *outstanding*, includes countries with high production and which grew in 2003–2008, with a normalized impact stabilized at high levels, and high subject specialization. The countries in this group appear in the upper right quadrant of Fig. 1, and the lower right quadrant of Fig. 2. The prime example of this group would be Turkey, and we would also include Greece, Sweden, India, The Netherlands, Spain, Australia, Italy, Canada, and the U.K.

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

Table 1
Temporal evolution of number of papers published, percentage variation from 2003 to 2008, and subject specialization index (SSI) by country (period 2003–08).

Country	Code	Ranking	Ndoc						Total Ndoc	PV	SSI
			2003	2004	2005	2006	2007	2008			
United States	USA	1	356	329	311	476	404	445	2321	25	0.58
China	CHN	2	84	96	135	205	295	362	1177	331	0.77
United Kingdom	GBR	3	118	141	142	196	242	249	1088	111	1.00
India	IND	4	85	101	103	152	227	272	940	220	2.48
Turkey	TUR	5	90	95	105	200	186	239	915	166	4.86
Japan	JPN	6	179	95	161	149	126	159	869	−11	0.84
Germany	DEU	7	101	116	93	149	127	124	710	23	0.73
Canada	CAN	8	82	57	69	127	120	155	610	89	1.04
Italy	ITA	9	77	73	72	99	120	143	584	86	1.05
Sweden	SWE	10	64	102	102	121	89	90	568	41	2.73
Spain	ESP	11	47	65	97	110	97	131	547	179	1.23
France	FRA	12	60	56	58	97	87	105	463	75	0.67
Australia	AUS	13	52	63	50	78	108	109	460	110	1.19
Greece	GRC	14	53	46	48	86	97	109	439	106	4.00
Netherlands	NLD	15	53	48	74	83	76	105	439	98	1.44
Denmark	DNK	16	33	39	36	60	74	54	296	64	2.65
Brazil	BRA	17	31	48	28	37	62	81	287	161	1.08
Switzerland	CHE	18	27	46	61	41	57	50	282	85	1.27
South Korea	KOR	19	47	19	25	46	58	75	270	60	0.78
Taiwan	TWN	20	31	27	42	42	55	72	269	132	1.14
Mexico	MEX	21	32	54	26	71	32	27	242	−16	2.45
Hong Kong	HKG	22	31	27	28	48	49	57	240	84	2.22
Belgium	BEL	23	32	24	32	44	55	41	228	28	1.32
Thailand	THA	24	25	15	36	32	47	54	209	116	3.68
Finland	FIN	25	22	32	22	34	45	40	195	82	1.80
Iran	IRN	26	5	7	10	22	45	75	164	1400	1.78
Austria	AUT	27	14	21	15	28	36	30	144	114	1.21
Portugal	PRT	28	10	15	19	33	33	33	143	230	1.84
Egypt	EGY	29	15	19	25	25	26	30	140	100	3.16
Norway	NOR	30	13	17	21	16	32	31	130	138	1.51
Poland	POL	31	14	13	19	22	25	30	123	114	0.64
Malaysia	MYS	32	14	11	14	14	31	21	105	50	3.08
South Africa	ZAF	33	9	13	12	21	23	23	101	156	1.55
Israel	ISR	34	20	18	9	17	13	21	98	5	0.75
Ireland	IRL	35	4	13	13	24	23	18	95	350	1.61
New Zealand	NZL	36	9	14	6	17	35	13	94	44	1.29
Russian Federation	RUS	37	11	10	14	16	20	21	92	91	0.29
Singapore	SGP	38	11	14	17	13	21	16	92	45	0.99
Jordan	JOR	39	24	15	8	7	9	25	88	4	8.08
Algeria	DZA	40	9	10	10	9	9	26	73	189	5.52
Tunisia	TUN	41	6	6	16	6	16	23	73	283	3.65
Slovenia	SVN	42	7	5	10	16	18	15	71	114	2.47
Saudi Arabia	SAU	43	11	10	13	8	15	9	66	−18	2.86
Argentina	ARG	44	7	13	7	3	13	22	65	214	1.00
Uzbekistan	UZB	45	1	1		12	31	16	61	1500	17.05
Romania	ROU	46	10	3	10	11	10	12	56	20	1.31
Czech Republic	CZE	47	6	4	8	9	12	14	53	133	0.61
Nigeria	NGA	48	8	10	3	6	9	17	53	113	2.32
Sri Lanka	LKA	49	11	8	11	7	9	6	52	−45	10.21
Morocco	MAR	50	3	12	7	18	2	9	51	200	3.85
World			2011	2033	2252	3070	3093	3637	16,096	81	

Somewhat peripheral in the group would be Sweden, given its low increase in production, and Italy, given the growth in its normalized impact.

- The second group, which we label as *advanced*, are countries characterized, like the previous group, by a high production, but now this production is fairly stable, and by a high and increasingly normalized impact, but without obtaining good values in subject specialization. The countries in this group appear in the upper left quadrants of Figs. 1 and 2. The prime example of this group would be the U.S., and we would also include France, Germany, China, and Japan. Peripheral in the group would be China, which has a very high value of growth in production, and France, with its relatively high value of increase in normalized impact.
- The third group, which we label as *intermediate*, is characterized by low production, low stabilized normalized impact, and low specialization. However, production increased during the period studied. They are not represented in Figs. 1 and 2 because their production is less than 200 documents, but if they had been, they would have been positioned in the lower left quadrant of Fig. 1. The prime example of this group would be Russia, and we would also include Poland, Israel, and South Korea. Peripheral in the group would be Israel because of its low percentage variation in production.
- The fourth group, which we label as *specialists*, consists of countries which are characterized by a medium-low but growing production, above-average subject specialization, and high and growing normalized impact. The prime example of this group would be Algeria, and we would also include Austria, Switzerland, Denmark, Belgium, Hong Kong, Norway, Taiwan, Malaysia, Singapore, Argentina, the Czech Republic, Mexico, Morocco, Saudi Arabia, and Sri Lanka. The most peripheral are Sri Lanka and Saudi Arabia because of their percentage variation in production, Morocco and Malaysia because of their percentage variation in normalized impact, and the Czech Republic because of its subject specialization index. Some of these countries are represented in the upper right quadrant of Fig. 1

Table 2
Total citation of all the papers, citation per papers, Percentage of cited papers, temporal evolution of the normalized impact, normalized impact, and percentage variation in the normalized impact (period 2003–08) per country, ordered by normalized impact.

Country	Total citation	Citation per paper	Percent. of cited papers	Normalized impact						Normalized impact	PV norm. impact
				2003	2004	2005	2006	2007	2008		
Denmark	4422	14.94	86.49	0.85	1.68	1.76	2.21	1.66	2.9	1.92	241
Austria	1974	13.71	81.25	1.67	1.21	1.19	0.7	2.91	0.94	1.52	−44
Netherlands	7458	16.99	83.14	2.07	1.03	1.46	1.11	1.53	1.58	1.46	−24
Switzerland	4253	15.08	81.91	1.39	1.12	1.57	1.32	1.43	1.79	1.45	29
Belgium	3195	14.01	80.7	1.71	1.08	1.02	1.68	1.28	1.05	1.32	−39
Germany	8992	12.66	80.7	1.16	1.38	1.34	1.05	1.4	1.58	1.31	36
Sweden	8195	14.43	83.63	1.63	1.21	1.49	1.12	1.03	1.3	1.27	−20
Turkey	19,295	21.09	77.49	1.58	1.58	1.56	0.97	0.98	1.25	1.24	−21
Hong Kong	3722	15.51	86.67	0.82	1.17	1.01	1.13	1.4	1.47	1.22	79
Norway	2341	18.01	80.77	0.84	1.49	1.1	0.84	1.88	0.85	1.22	1
Greece	5823	13.26	82	1.45	1.16	1.19	1.05	1.05	1.38	1.21	−5
Taiwan	4135	15.37	81.78	1.17	1.17	0.99	1.76	1.3	0.83	1.17	−29
United Kingdom	11,012	10.12	75.28	1.33	1.02	0.98	1.5	1.06	1.11	1.16	−17
India	10,518	11.19	71.7	1.29	1.22	1.39	1.26	0.99	1.01	1.14	−22
Malaysia	1147	10.92	65.71	1.47	0.98	1.42	1.11	0.95	1.07	1.14	−27
China	15,849	13.47	71.79	0.99	1.39	1.11	1.31	1.15	0.99	1.13	0
Singapore	1333	14.49	81.52	1.14	1.21	1.1	1.3	0.89	1.26	1.13	11
Argentina	522	8.03	84.62	1.95	0.58	0.46	0.34	1.54	1.19	1.1	−39
Australia	4836	10.51	71.96	1.16	1.12	0.94	1.32	1.1	0.92	1.09	−21
France	5806	12.54	79.48	0.93	1.09	0.82	1.02	1.21	1.27	1.09	37
Algeria	610	8.36	76.71	0.74	0.58	1.26	2.08	1.3	0.9	1.08	22
Czech Republic	633	11.94	71.7	1.05	2.75	1.19	1.05	0.28	1.19	1.08	13
Spain	6791	12.41	80.44	1.02	0.95	1.23	1.21	0.98	1.03	1.08	1
Mexico	2338	9.66	76.45	1.21	1.19	0.99	1.09	1.04	0.67	1.06	−45
United States	27,718	11.94	65.14	0.99	0.92	0.96	1.07	1.27	1.03	1.04	4
Morocco	715	14.02	80.39	1.46	0.75	1.01	1.47	0.71	0.3	1.01	−79
Saudi Arabia	1179	17.86	81.82	1.22	1.83	0.84	1.02	0.44	1.02	1.01	−16
Canada	8213	13.46	71.31	1.21	1.09	1.18	0.92	1.08	0.8	1	−34
Italy	7998	13.7	75.86	0.97	1.15	1	0.89	0.94	1.07	1	10
Sri Lanka	435	8.37	73.08	0.54	1.28	1.45	0.61	0.98	1.23	1	128
Ireland	1037	10.92	81.05	1.32	1.4	0.84	1.05	0.92	0.67	0.98	−49
South Korea	2879	10.66	73.7	0.91	1.3	1.1	1.18	1.02	0.71	0.97	−22
Japan	10,686	12.3	73.88	0.84	1.04	0.96	1.01	1.05	0.94	0.96	12
Thailand	2141	10.24	78.95	0.89	0.64	0.84	1.11	1.05	0.97	0.95	9
New Zealand	1591	16.93	70.21	0.94	1.72	1.13	0.39	0.87	0.77	0.94	−18
Brazil	2905	10.12	79.09	0.94	0.69	0.6	0.92	0.94	1.17	0.92	24
South Africa	621	6.15	71.29	0.37	0.58	0.88	0.71	1.49	0.99	0.92	168
Finland	1390	7.13	76.92	0.68	0.79	1.02	1	0.97	0.75	0.88	10
Slovenia	538	7.58	80.28	0.87	0.67	0.94	0.88	1.03	0.76	0.88	−13
Poland	1116	9.07	71.54	1.02	0.86	0.77	0.55	0.67	1.28	0.87	25
Portugal	1364	9.54	71.33	0.83	0.95	0.45	1.04	0.72	0.95	0.84	14
Israel	1031	10.52	70.41	0.87	0.65	0.36	0.69	1.35	0.9	0.82	3
Iran	1348	8.22	70.73	0.86	0.89	0.83	1.01	0.65	0.74	0.77	−14
Romania	544	9.71	82.14	0.56	1.08	0.81	0.91	0.51	0.67	0.72	20
Tunisia	416	5.7	68.49	0.73	0.45	0.81	0.44	0.48	0.85	0.68	16
Jordan	1427	16.22	68.18	0.7	1.34	0.64	0.42	0.54	0.34	0.67	−51
Egypt	1475	10.54	69.29	0.62	0.85	0.67	0.79	0.64	0.34	0.64	−45
Nigeria	535	10.09	60.38	1.13	0.91	1.12	0.31	0.66	0.26	0.64	−77
Russian Federation	510	5.54	51.09	0.57	0.5	0.64	0.52	0.42	0.44	0.5	−23
Uzbekistan	37	0.61	14.75	0.1	0		0.22	0.06	0	0.07	−100
World	335,338	20.83									

(both their SSI and their normalized impact exceed the global average).

- Finally, the fifth group, which we label as *initiates*, consists of countries with low but growing production, low stable normalized impact, and high subject specialization. If they had been represented in Figs. 1 and 2, most of them would be found in the lower right quadrants of both figures. The prime example of this group would be Uzbekistan, and we would also include Jordan, Thailand, Tunisia, Egypt, Slovenia, Nigeria, Portugal, Finland, Iran, Ireland, South Africa, Romania, New Zealand, and Brazil. Jordan is peripheral because of its percentage variation in production, as also is South Africa because of its high percentage variation of normalized impact.

We identified a total of 2189 institutions with production in Renewable Energy, Sustainability and the Environment worldwide. Table 3 lists those with a production of at least 50 documents. Of these institutions, 40 are universities and 11 governmental. In addition to the total production in the period studied, the table lists their cites, cites per document, percentage of cited documents, and normalized impact.

The Technical University of Denmark is the institution with the greatest number of documents obtained in the period 2003–08, and also has the best normalized impact value (Fig. 3); in total cites, it descends to rank fifth, reflecting the major increase in its production during the period. It is followed by the Chinese Academy of Sciences, which is the institution with the greatest number of cites in the period, and Shanghai Jiao Tong University which, however, is several positions down in normalized impact (Fig. 3).

Karadeniz Technical University is the top-ranked institution in terms of cites per document, and also obtained a good normalized impact value. For this indicator, the institutions with greatest production descend considerably in ranking.

With respect to the percentage of cited documents, Chalmers University of Technology is the foremost institution.

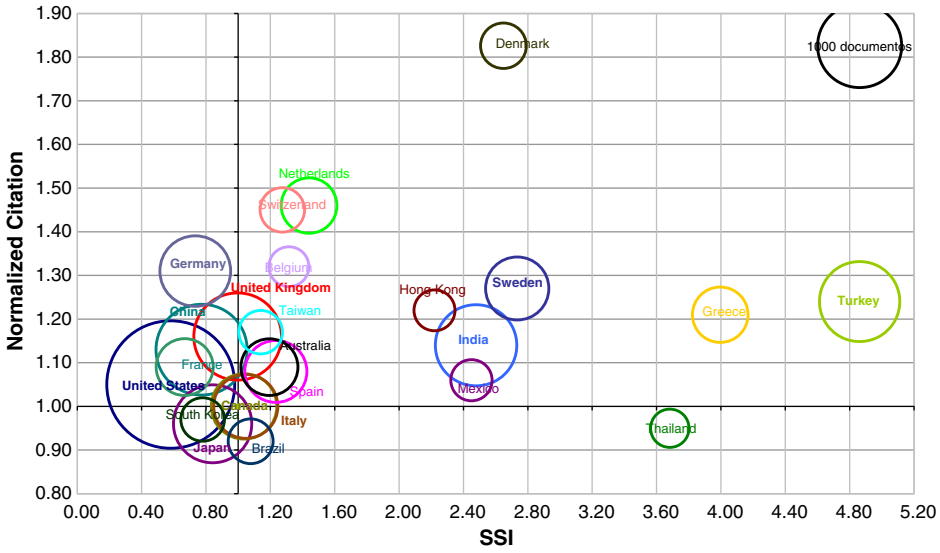

Fig. 1. Subject specialization index and normalized impact of countries with a production of at least 200 documents (period 2003–08). The horizontal and vertical axes represent the global averages, and they are used to define the quadrants mentioned in the text.

For the normalized impact, over 80% of the institutions are above the world average (i.e., with values above 1).

The countries with most institutions in the list are Sweden and Turkey (6 each), followed by China and the U.S. (5 each), and Japan (3).

Fig. 3 shows the production and normalized impact of the institutions with a production of at least 70 documents. The symbols in the figure distinguish the countries to which each institution belongs.

One can establish six groups of institutions according to the values of the indicators of Table 3:

- Group 1 is dominated by Chinese institutions, and includes the most complete in the sense of being characterized by having the most documents, more cites per document, and a greater normalized impact. "Utrecht University" is the prime example of this group. One can also include the following institutions: "Chinese Academy of Sciences", "Shanghai Jiao Tong University", "Indian Institute of Technology, Delhi", "Tsinghua University", "National Institute of Advanced Industrial Science and Technology", "Centre for Energy, Environment and Technology", and "Ege University".
- Group 2 is characterized, like the previous group, by institutions with high production and increasing normalized impact, but in this case fewer cites per document. This reflects their major increase in production and normalized impact over the course of the period studied. The prime example of this group is the "Technical University of Denmark". One can also include: "Swiss Federal Institute of Technology", "Centre National de la Recherche Scientifique", "Universidad Nacional Autonoma de Mexico", "Hong Kong Polytechnic University", and "Delft University of Technology".
- Group 3 comprises those institutions that have high levels of scientific production, but low levels of cites per document and normalized impact. The prime example of this group is the "National Renewable Energy Laboratory". As well as this U.S. institution, there is a Greek university, the "National Technical University of Athens".

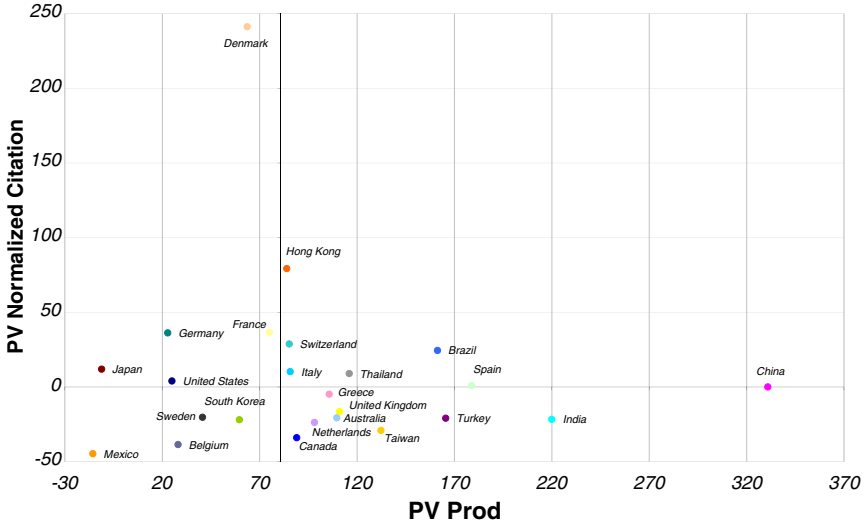

Fig. 2. Percentage variation of production, and percentage variation in normalized impact of the countries producing at least 200 documents (period 2003–08). The horizontal and vertical axes represent the global averages, and they are used to define the quadrants mentioned in the text.

Table 3
Most productive institutions in the subject category Renewable Energy, Sustainability and the Environment (institutions with a production of at least 50 documents; period 2003–08).

Institution	Country	Ndoc	Cites	Cites per document	% Cited documents	Normalized citation
Technical University of Denmark	DNK	181	1966	10.86	64.64	2.22
Chinese Academy of Sciences	CHN	176	2994	17.01	76.14	1.28
Shanghai Jiao Tong University	CHN	158	2621	16.59	80.38	1.09
Centre National de la Recherche Scientifique	FRA	133	1731	13.02	73.68	1.22
Universidad Nacional Autonoma de Mexico	MEX	125	1351	10.81	77.6	1.21
National Renewable Energy Laboratory	USA	123	1189	9.67	50.41	0.81
Hong Kong Polytechnic University	HKG	108	1486	13.76	88.89	1.2
National Technical University of Athens	GRC	104	1408	13.54	65.38	0.88
Indian Institute of Technology, Delhi	IND	96	1819	18.95	81.25	1.55
Swiss Federal Institute of Technology	CHE	95	1269	13.36	52.63	1.41
Tsinghua University	CHN	91	1434	15.76	80.22	1.45
National Institute of Advanced Industrial Science & Technology	JPN	87	1431	16.45	73.56	1.26
Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas	ESP	86	1730	20.12	81.4	1.18
Lund University	SWE	85	1233	14.51	87.06	1.54
Delft University of Technology	NLD	84	954	11.36	83.33	1.09
Ege University	TUR	83	1632	19.66	83.13	1.28
Utrecht University	NLD	80	2784	34.8	91.25	2.13
Lawrence Berkeley National Laboratory	USA	78	1325	16.99	80.77	1.28
Uppsala University	SWE	78	690	8.85	69.23	1.5
Istanbul Technical University	TUR	78	1929	24.73	70.51	1.26
Fraunhofer Gesellschaft	DEU	78	600	7.69	66.67	1.46
Marmara University	TUR	77	39	0.51	3.9	1.39
Selcuk University	TUR	76	1038	13.66	51.32	1.28
Universidad Politecnica de Madrid	ESP	75	732	9.76	72	0.81
University of Colorado, Boulder	USA	75	433	5.77	41.33	0.64
Chalmers University of Technology	SWE	74	1482	20.03	94.59	1.41
Deutsches Zentrum fur Luft- und Raumfahrt	DEU	69	871	12.62	50.72	0.6
Imperial College London	GBR	68	755	11.1	77.94	1.39
University of New South Wales	AUS	65	1088	16.74	84.62	1.33
University of California, Berkeley	USA	64	978	15.28	78.13	1.31
Tokyo Institute of Technology	JPN	63	944	14.98	66.67	0.84
City University of Hong Kong	HKG	63	1127	17.89	82.54	1.26
Tongji University	CHN	63	743	11.79	73.02	0.94
Council of Scientific and Industrial Research	IND	62	584	9.42	53.23	1.38
University of Western Ontario	CAN	58	600	10.34	79.31	0.72
Swedish University of Agricultural Sciences	SWE	57	832	14.6	70.18	1.14
Zhejiang University	CHN	56	897	16.02	69.64	1.04
Gazi University	TUR	56	1239	22.13	67.86	1.22
Aalborg University	DNK	54	830	15.37	83.33	1.92
Aristotle University of Thessaloniki	GRC	54	538	9.96	83.33	1.24
Karadeniz Technical University	TUR	53	2226	42	73.58	1.58
University of Tokyo	JPN	53	708	13.36	69.81	0.93
National University of Singapore	SGP	53	768	14.49	83.02	1.31
University of Waterloo	CAN	52	1277	24.56	82.69	1.07
Norwegian University of Science and Technology	NOR	52	1422	27.35	76.92	1.63
Linkopings Universitet	SWE	51	362	7.1	70.59	1.19
Consiglio Nazionale delle Ricerche	ITA	50	478	9.56	70	1.1
Sandia National Laboratories, New Mexico	USA	50	184	3.68	18	0.19
Catholic University of Leuven	BEL	50	863	17.26	78	1.25
National Taiwan University	TWN	50	481	9.62	76	1.53
Royal Institute of Technology	SWE	50	1180	23.6	86	1.34

- Group 4 comprises mostly Swedish institutions, followed by Turkish and U.S. It is characterized, in contrast to the previous group, as being institutions with fewer documents, but more cites per document and greater normalized impact. The prime example of this group would be the "Karadeniz Technical University". The other institutions that fit in this group are: the "Lawrence Berkeley National Laboratory", "Istanbul Technical University", "Chalmers University of Technology", "University of New South Wales", "University of California, Berkeley", "City University of Hong Kong", "Gazi University", "Zhejiang University", "Aalborg University", "Norwegian University of Science and Technology", "University of Waterloo", "Royal Institute of Technology", "Catholic University of Leuven", "National University of Singapore", "Swedish University of Agricultural Sciences", and "Lund University". If production had not been considered as a variable in this group, the "Norwegian University of Science and Technology" and "Karadeniz Technical University" would fit better into Group 1 since they have very high values of normalized impact and citations per document.
- Group 5 is almost the inverse of Group 1 because it is characterized by institutions with low values of production, cites per document, and normalized impact. The prime example of this group is "Sandia National Laboratories, New Mexico". It also includes the "Deutsches Zentrum für Luft- und Raumfahrt", "Universidad Politecnica de Madrid", "University of Colorado, Boulder", "Tongji University", "Tokyo Institute of Technology", "University of Western Ontario", and "University of Tokyo", although "Tongji University" and the "University of Tokyo" approach the global averages of some variables.
- Finally, Group 6 is characterized by institutions with low values of production and cites per document, but a high normalized impact. The prime example of this group would be the "National Taiwan University", and the other institutions that would fit within this group would be: "Uppsala University", "Fraunhofer Gesellschaft", "Marmara University", "Selcuk University", "Imperial College London", "Council of Scientific and Industrial Research", "Aristotle University of Thessaloniki", "Linkopings Universitet", and "Consiglio Nazionale delle Ricerche". It has to be mentioned that "Marmara

University" stands out as being the institution of all the groups with fewest cites per document throughout the period.

Groups 1 and 5 are the groups most clearly differentiated from the rest, one with very high values for all the variables, and the other with very low values.

Listed in Table 4 are the total production of journals in the subject category under study, their percentage variation of production, cites, relative impact (SJR), the evolution of SJR by year, and the percentage variation of SJR.

In terms of scientific production, the journal "Energy Conversion and Management" (ECM) had the greatest number of documents in the period 2003–08, followed by "Solar Energy Materials and Solar Cells" (SEMSC). These were also the journals which received most cites in the period. They were followed by "Renewable Energy" (RENENE) and "Energy" (ENERGY) (Fig. 4).

Considering only the most productive journals, the greatest percentage variation in 2008 over 2003 corresponded to "Earth", followed by "Renewable and Sustainable Energy Reviews" and "Applied Solar Energy (English translation of Geliotekhnika)". "Solar Energy Materials and Solar Cells", which was second ranked in production, descended to the last positions in terms of percentage variation, reflecting its maintenance of a constant number of papers throughout the period.

Relating the two most productive journals with their impact, one observes that "Solar Energy Materials and Solar Cells" (SEMSC) drops to third place and "Energy Conversion and Management" (ECM) to seventh (Fig. 4). The journals that are ranked ahead of the latter in impact are "Annual Review of Environment and Resources" (ARERE), "Environmental Research Letters" (ERL), "Renewable and Sustainable Energy Reviews" (RSER), "Biomass and Bioenergy" (BIOMBIOE), and "Solar Energy" (SOLEN). It should be noted that this indicator does not vary greatly among the various journals, with only 25% of them surpassing the global average (0.065).

The journal with the greatest average annual growth in impact is "Annual Review of Environment and Resources" (ARERE), followed by "Biomass and Bioenergy" (BIOMBIOE). "Earth" (EARTH), which ranked fifth in terms of production, descends to the last position.

Fig. 4 shows the number of documents and the relative impact (SJR) of journals with a production of at least 200 documents.

One can establish five groups of journals according to the values of the indicators of Table 4:

- The journals of Group 1 can be considered the most complete since they are characterized by having a high number of documents, more cites in the period, and greater impact. The prime example of this group is the journal "Solar Energy Materials and Solar Cells". We would also include "Solar Energy", "Energy Conversion and Management", and "Biomass and Bioenergy", although this last journal is distant from the others in having fewer documents.
- The journals of Group 2 have high values of production and cites, but in this case their impact does not surpass the global average. "Renewable Energy" is the prime example of this group of journals. We would also include "Resources, Conservation and Recycling", "Journal of Cleaner Production", "Energy and Buildings", "Journal of Wind Engineering and Industrial Aerodynamics", and "Energy". The first of these, "Resources, Conservation and Recycling", is distant in the sense that it has less than half the number of documents of "Renewable Energy".
- Group 3 is characterized by journals with high values of production but low numbers of cites and SJR. The prime example would be "International Solar Energy Conference".
- Group 4 is very different from the first, being characterized by journals with few documents, few cites, and a low SJR. The prime example of this group would be "International Journal of Sustainable Development and Planning". We would also include "IET Renewable Power Generation", "International Journal of Innovation and Sustainable Development", "International Journal of Sustainable Energy", "International Journal of Green Energy", "Energy Sources, Part B: Economics, Planning and Policy", "Thermal Science", "Research Journal of Chemistry and Environment", "Wind and Structures, An International Journal", "Wind Energy", "International Journal of Photoenergy", "Journal of Energy Resources Technology, Transactions of the ASME", "Environmental Impact Assessment Review", "Environmental Progress and Sustainable Energy", "Energy and Environment", "Asia-Pacific Journal of Chemical Engineering", "Applied Solar Energy (English translation of Geliotekhnika)", and "Energy Sources, Part A: Recovery, Utilization and Environmental Effects", although the journal "Environmental Impact Assessment Review" comes close to the global averages in some of the variables.
- Group 5 is characterized by journals with few documents, a medium-low number of cites, but now a greater SJR. The prime example would be "Environmental Research Letters". We would also include "Annual Review of Environment and Resources", "Energy for Sustainable Development", "Environmental Science and Policy", and "Renewable and Sustainable Energy Reviews". "Annual Review of Environment and Resources" is the journal that has the highest impact, not only in this group, but of all the journals in the study.

Conclusions

The analysis has shown that total world production increased over the course of the period studied (2003–08), and that some developing countries stand out in the world as a whole for some of the variables studied.

During this period, the U.S., China, U.K., India, Turkey, and Japan were the countries with the greatest production and most cites, and China was the country with the greatest increase in production. Turkey and Greece, however, showed the greatest relative effort being made in Renewable Energy, Sustainability and the Environment. The countries with the greatest impact were Denmark, The Netherlands, Switzerland, Belgium, and Germany, with the first of these having the greatest increase in this period.

The countries can be classified into 5 groups:

- Outstanding countries — These are highly specialized, and have a high level of internationally recognized scientific production which increased considerably over the period studied.
- Advanced countries — These are international powers with a high, stable, and internationally recognized scientific production, which is the result of volume rather than any particular specialization.
- Intermediate countries — Their scientific production is small in volume and not well recognized, with a concomitant low level of subject specialization despite their having experienced high growth.
- Specialist countries — They have just a low to medium volume of production, but one that is growing and is highly specialized, as a result of which they achieve a high and growing value of normalized impact.
- And finally, initiate countries — These have limited scientific production, and consequently can obtain values of subject specialization which are fairly high, although not statistically significant. Their impact is low, and varied little during the period studied.

The institutions were classified into 6 groups:

- The first consists of institutions with high scientific production and impact throughout the period.
- The second are institutions also with high levels of production and impact, but which are recent as reflected in their rapid growth in the period.
- The third are institutions that have high production but low impact.
- The fourth are institutions with medium production but notable impact.
- The fifth are institutions with little production and low impact.

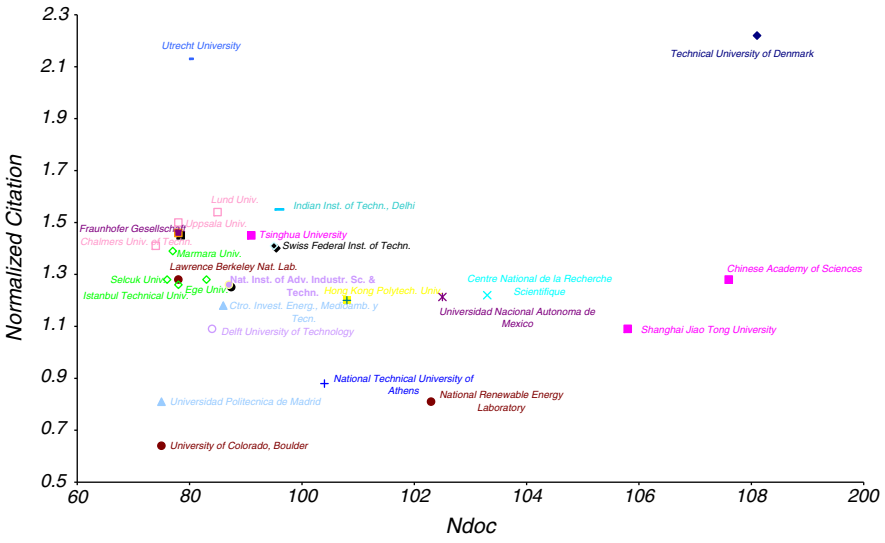

Fig. 3. Number of documents and normalized impact of institutions with a production of at least 70 documents (period 2003–08).

- And the sixth and final group are institutions of very low but recent production with increasing impact.

As the first three groups of institutions have the highest scientific production, they also have the greatest weight in determining the performance of their respective countries. The first group includes institutions which are the leaders in this field in their countries, and are the cause of most of their countries having been classified as "outstanding", or "advanced" in this sense. The case is similar with the group 2 institutions, but in this case there are some countries that were still classified as "specialists". The countries of the two institutions in the third group also were classified as "advanced" or "outstanding".

Table 4
Total documents, PV in production, cites, SJR (SCImago Journal Rank), evolution of SJR, and PV of the SJR for journals (period 2003–08).

Title	Abbrev.	Total docs.	PV prod	Cites	SJR	SJR 2003	2004	2005	2006	2007	2008	PV SJR
Energy Conversion and Management	ECM	1682	97.69	6362	0.071	0.061	0.062	0.072	0.073	0.073	0.085	39.34
Solar Energy Materials and Solar Cells	SEMSC	1588	−14.90	9704	0.157	0.14	0.113	0.13	0.16	0.168	0.23	64.29
Renewable Energy	RENENE	1156	77.19	3652	0.063	0.054	0.055	0.06	0.06	0.068	0.08	48.15
Energy	ENERGY	1146	108.42	3486	0.063	0.057	0.053	0.055	0.072	0.063	0.08	40.35
Earth	EARTH	958	1242.11	48	0.034	0.038	0.036	0.034	0.036	0.032	0.03	−21.05
Energy and Buildings	ENBUILD	943	141.82	2546	0.060	0.057	0.055	0.055	0.058	0.065	0.07	22.81
Journal of Cleaner Production	JCLEPRO	920	160.00	2402	0.052	0.053	0.058	0.049	0.051	0.05	0.05	−5.66
Solar Energy	SOLEN	890	30.61	4019	0.091	0.085	0.061	0.074	0.097	0.119	0.107	25.88
Biomass and Bioenergy	BIOMBIOE	669	57.45	3692	0.101	0.069	0.074	0.076	0.141	0.107	0.14	102.90
International Solar Energy Conference	ISEC	657	−100.00	29	0.033	0.038	0.036	0.034	0.031	0.029	0.03	−21.05
Journal of Wind Engineering and Industrial Aerodynamics	JWEIA	533	37.61	1319	0.052	0.051	0.053	0.051	0.049	0.056	0.05	−1.96
Resources, Conservation and Recycling	RESCONREC	500	65.63	1670	0.060	0.058	0.065	0.056	0.063	0.059	0.06	3.45
Energy Sources, Part A: Recovery, Utilization and Environmental Effects	ESPARUEE	453		197	0.037					0.034	0.04	
Applied Solar Energy (English translation of Geliotekhnika)	ASE	409	338.89	10	0.033	0.038	0.036	0.034	0.031	0.03	0.03	−21.05
Asia-Pacific Journal of Chemical Engineering	APJCE	396	93.48	134	0.036	0.042	0.039	0.036	0.034	0.033	0.03	−28.57
Energy and Environment	ENENV	389	53.66	330	0.043	0.041	0.044	0.047	0.059	0.035	0.03	−26.83
Renewable and Sustainable Energy Reviews	RSER	367	374.07	1707	0.102	0.088	0.087	0.097	0.067	0.132	0.14	59.09
Environmental Science and Policy	ENSP	348	20.75	1345	0.070	0.096	0.063	0.056	0.058	0.065	0.081	−15.63
Environmental Progress and Sustainable Energy	EPSE	281	28.26	592	0.055	0.054	0.051	0.05	0.063	0.051	0.06	11.11
Environmental Impact Assessment Review	EIAR	255	32.35	1066	0.055	0.05	0.05	0.057	0.053	0.06	0.06	20.00
Journal of Energy Resources Technology, Transactions of the ASME	JERTTASME	246	−2.38	404	0.044	0.05	0.046	0.042	0.048	0.039	0.04	−20.00
Energy for Sustainable Development	ESD	225	−7.69	247	0.065	0.043	0.039	0.15	0.039	0.066	0.05	16.28
International Journal of Photoenergy	IJP	211	42.86	354	0.064	0.051	0.067	0.072	0.068	0.068	0.06	17.65
Wind Energy	WINEN	204	66.67	574	0.056		0.047	0.045	0.059	0.061	0.07	
Wind and Structures, An International Journal	WSIJ	188	10.00	288	0.043	0.047	0.046	0.043	0.042	0.04	0.04	−14.89
Environmental Research Letters	ERL	146		113	0.192					0.253	0.13	
Research Journal of Chemistry and Environment	RJCE	121		15	0.030						0.03	
Energy Sources, Part B: Economics, Planning and Policy	ESPBEPP	114		56	0.036					0.031	0.04	
Thermal Science	THSC	114		14	0.030						0.03	
International Journal of Green Energy	IJGE	111		36	0.038					0.036	0.04	
Annual Review of Environment and Resources	ARER	98	5.26	1006	0.302	0.269	0.096	0.239	0.36	0.258	0.59	119.33
International Journal of Sustainable Energy	IJSE	84	−15.79	52	0.038	0.041	0.037	0.043	0.039	0.035	0.03	−26.83
International Journal of Sustainable Development and Planning	IJSDP	80		8	0.030					0.03	0.03	
International Journal of Innovation and Sustainable Development	IJISD	68		41	0.032				0.033	0.032	0.03	
World Review of Entrepreneurship, Management and Sustainable Development	WREMSD	52			0.030						0.03	
IET Renewable Power Generation	IETEPG	49		43	0.060						0.06	

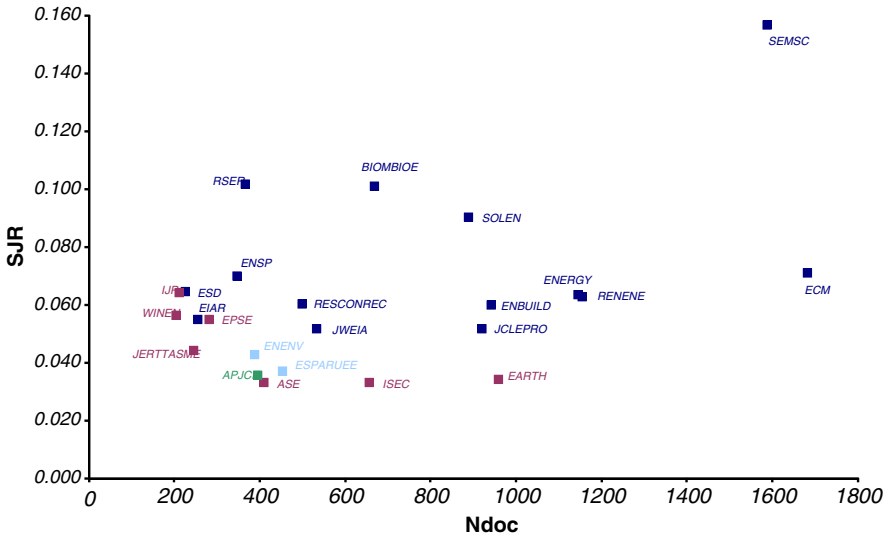

Fig. 4. Ndoc and SJR of journals in the subject category Renewable Energy, Sustainability and the Environment (production of at least 200 documents; period 2003–08).

The other three groups correspond to institutions with little scientific production, and which therefore have little weight in the production of their respective countries.

And finally, 5 groups were established for the journals used in the study:

- The first group consists of journals which, with a high scientific production, achieve a high impact.
- The second group consists of journals of high production but below-average impact.
- The third group consists of journals of high production but very low impact.
- The fourth group consists of journals with a low publication volume and little impact.
- The fifth group consists of journals with a low publication volume but high impact.

As we said at the beginning, although the indicators used are to study the quantity and quality of scientific publications, they may not represent the importance of the issues treated.

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