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The structure and sources of energy science

This article is an effort to identify the structure and sources of non-nuclear energy related science. Based on the principle that the knowledge base of any field is to be found in its published literature and that any new information builds upon past publications, citation analysis of the energy related journals is employed. The analysis reveals that chemical disciplines provide most of the contributions to energy science. The USA is found to be the major contributor of energy related literature followed by West Germany and the UK. Policy implications for academic, research and research-funding institutions are discussed.

Keywords: Energy science; Literature sources; Policy

Energy science as an individual scientific discipline took off after the oil crisis of the early 1970s. Since then the number of scientific journals specializing in energy has almost doubled[1] and universities started offering courses tailored to energy technology and energy management. A need which sprang out of this increased activity is the analysis of the new scientific discipline in order to identify its structure and sources. Structure identification is taken to mean the contribution of traditional scientific disciplines (eg physics, chemistry, engineering etc) in the make of the discipline of energy and as sources are defined the countries of origin of energy related contributions to energy literature. This article is an attempt to analyse these questions. Such an analysis can be used for the evaluation and formulation of energy research policy, the structure of curricula of energy courses and energy related environmental scanning. For example, knowledge of the national contribution to energy science can justify the budgets allocated for energy research and can facilitate the scanning process at a company or a national level in order to identify and acquire new technologies at an early stage when they are cheaper. Similarly the recognition that say chemistry is the foundation stone in energy research could encourage academic institutes to emphasize chemistry in their curricula and ensure that funds for research are allocated within the field so that they bring the maximum return. We first outline the methodology used in this analysis and then present our results. The article ends with some conclusions and policy implications.

Methodology

In order to identify the structure and sources of energy science, we employ publication and citation analysis. The rationale behind this method is that the knowledge base of any field is its published literature and any new information and contribution grows out of past publications. Citation analysis has been used to identify and map research fronts[2,3] to evaluate science policy[4,5] and to evaluate research institutes, researchers, scientific journals and papers.[6,7,8]

The procedure is to obtain a scientific literature network by linking each journal to other journals associated with it. The linking bonds are the citations or references in the articles published by a journal to other articles published elsewhere. The most comprehensive source of data for science citation analysis is provided by the Institute for Scientific Information (ISI) in its *Science Citation Index*, *Journal Citation Reports* (*SCI*, *JCR* 1983). The *SCI*, *JCR* provides citation data of science journals which are indexed by the *Science Citation Index* (*SCI*), *Social Science Citation Index* (*SSCI*) and the *Arts and Humanities Citation Index* (*A & HCI*). In the *JCR* there are tabulations showing for each individual journal, the names of journals cited in it, and the journals that cite this particular journal. In the 1983 issue the *SCI*, *JCR* is based on approximately 10.5 million citations derived from the references of over one million articles published in the 1983 issues of around 7 000 journals, processed by the ISI. One of the *SCI*, *JCR* listings classifies the source journals in 129 subject disciplines (ie chemistry, mechanics, optics, economics, geology etc) The journals are classified into disciplines according to the citation patterns of the articles published in them and therefore the problems associated with changes in editorial policies, emphasis on different subjects, misleading titles and so on are avoided.

One of the categories 'Energy and fuels', covers the energy field and consists of 26 energy related journals. These journals consist of the 'core'[9] journals in the field of energy science and they are an adequate representation[10] of the more than 500 journals and periodicals with titles incorporating the word energy or other related words which are listed in the 1984 edition of *Ulrich's International Periodicals Directory* and the *Regular Serials and Annuals – An International Directory 1984* of RR Bowker.

By allocating the references in each of these 26 journals to the journals of origin (where the reference is referred to) and allocating the journals to disciplines, it is possible to infer the specific nature of each journal. Considering all the core journals of the field as a 'macro-journal of the energy science' and combining their references, the scientific disciplines contributing most to the energy field can be identified.

The sources of energy science were

Table 1. Specific nature of energy science journals (% of citations allocated to scientific disciplines).

	Energy and fuel	Multidisciplinary	Meteorology and atmospheric science	Mechanics	Mechanical engineering	Applied sciences	Physical chemistry	Chemistry	Geosciences	Chemical engineering	Environmental studies	Aerospace	Physics, fluids	Oceanography	Civil engineering	Analytical chemistry	Electrochemistry	Metallurgy	Physics, condensed matter	Engineering	Cancer	Physics
Annual Review of Energy	66.7	33.3																				
Applied Energy	72.0	3.4	2.9	5.4	4.4	3.9																
Carbon	52.9	5.0				2.2	13.8	6.6								0.9		0.8	5.4			2.9
Chemistry and Physics of Carbons																						
Combustion and Flame	48.6	6.1		2.0	0.5	1.7	8.5	2.9		2.9		5.4	3.0			2.0				1.3		
Combustion Science and Technology	70.0			4.1	1.4		2.7			2.5		12.4								1.4		
Energy	66.7	15.7									7.8											
Energy Conversion and Management	86.9					2.5						6.6	4.1									
Erdol & Kohle Erdgas Petrochemie	48.7						6.5	9.4	3.2	28.7						4.2						
Fuel	57.6	3.1				0.3	4.6	7.9	1.0	6.7	0.4					9.2		0.3				
Fuel Processing Technology	68.0							4.5		9.0						7.1		2.1				
Hydrocarbon Processing	60.0						3.3	4.0		31.6												
International Journal of Energy Research	75.7			4.3	5.7		4.3															
International Journal of Hydrogen Energy	42.3	3.0					3.0	2.6									22.6	14.1	3.0			
Journal Energy	60.7											12.5	19.6									
Journal of Energy Resources Technology	21.0		16.8	8.4	7.3				12.6	6.3					6.3					13.6		
Journal of Energy Engineering – ASCE	15.4										38.5			30.8	15.4							
Journal of the Institute of Energy	91.5									8.5												
Journal of Petroleum Technology	71.9		1.6							20.8												
Journal of Solar Energy Engineering	66.0			21.1	11.0	1.8																
Petroleum Chemistry MSSR																						
Progress in Energy and Combustion Science	45.3	6.1			12.1					5.7	5.7	5.3								10.9		
Solar Petroleum Engineering Journal	77.3		1.3	0.9			8.4	2.2		1.3												
Solar Cells	9.0	0.8				30.6	0.5	0.5									2.6		13.3			21.7
Solar Energy	66.8	1.8	12.8	1.2	1.2	3.0	1.7	1.5	0.9													
Solar Energy Matter	17.6	4.3				31.6	3.5	2.7									20.2		2.4			5.3

identified by allocating the articles published in the 'core' energy journals to corporate addresses. A count was made of publications (ie articles, notes and reviews) associated with different national research-producing institutions. For example, if an author gave as a corporate address the University of Cape Town, the publication would be assigned to South Africa. To this end, the SCISEARCH date file was used through DIALOG Information Service.

SCISEARCH is an international, multi-disciplinary index to the literature of science, technology, biomedicine and related disciplines produced by ISI. SCISEARCH contains all the records published in *SCI* bi-monthly issues, plus additional records from the 'current contents' series of publications.

The names of the 'core' energy journals were combined with the names of countries in order to calculate the number of publications that are allocated to each country. The search covered all issues published in the period 1984 to 1986 (28 weeks).

Structure and sources of energy science

In Table 1 the 'core' energy journals are shown and the percentage of the cited references in them allocated to a variety of main disciplines.[11] The disciplines are those listed in the *Journal Ranking Package* of the *SCI*, *JCR*. When a journal is listed under two or more categories the number of references is divided between all disciplines. When the journal belongs to the 'energy and fuels' group and to another discipline as well, all references are allocated to the 'energy and fuels' group. Only references listed individually in the *Citing Journals Package* are taken into account.

From Table 1, the disciplines combined in each journal to provide new

Table 2. Country contributions to energy journals.

	W Germany	South Africa	USA	Canada	Brazil	France	Australia	India	UK	Sweden	Mexico	Japan
Annual Review of Energy	1	0	36	0	2	1	0	1	0	1	0	0
Applied Energy	1	0	9	0	0	3	1	17	59	2	0	4
Carbon	32	0	260	23	2	48	3	7	47	1	0	65
Chemistry and Physics of Carbons	0	0	1	0	0	0	0	0	1	0	0	0
Combustion and Flame	11	0	173	15	1	13	17	3	42	3	3	24
Combustion Science and Technology	3	0	92	3	0	14	2	7	15	1	2	12
Energy	3	0	123	7	2	1	3	13	4	1	5	10
Energy Conversion and Management	5	0	17	2	0	0	2	92	4	0	1	6
Erdol & Kohle Erdgas Petrochemie	285	0	16	3	0	2	3	7	8	1	0	2
Fuel	34	1	373	59	1	28	83	15	75	2	4	93
Fuel Processing Technology	3	2	66	9	0	11	11	5	3	0	0	25
Hydrocarbon Processing	12	0	253	11	0	13	1	3	9	0	0	6
International Journal of Energy Research	0	0	13	5	0	5	2	26	16	1	0	5
International Journal of Hydrogen Energy	35	1	74	40	3	9	0	9	3	2	0	25
Journal Energy	0	0	46	4	0	0	2	0	3	0	1	1
Journal of Energy Resources Technology	3	1	129	22	0	4	0	2	20	0	0	18
Journal of Energy Engineering – ASCE	0	0	32	2	0	0	0	2	1	0	0	1
Journal of the Institute of Energy	0	0	13	3	0	0	5	3	41	0	0	0
Journal of Petroleum Technology	2	0	274	12	0	3	3	1	19	0	1	1
Journal of Solar Energy Engineering	1	1	119	9	1	2	4	1	1	0	1	10
Petroleum Chemistry MSSR	0	0	8	0	0	0	0	0	0	0	0	10
Progress in Energy & Combustion Science	1	0	27	1	0	1	1	0	0	1	0	0
Solar Petroleum Engineering Journal	1	0	126	13	0	5	0	0	2	0	7	0
Solar Cells	5	0	80	1	5	20	2	21	7	1	2	10
Solar Energy	13	0	186	23	3	14	39	25	22	4	3	14
Solar Energy Matter	15	0	51	7	1	11	9	11	10	15	3	8
Total	466	6	2597	271	21	208	192	271	413	35	34	340

information related to energy can be identified. For example, in the journal *Solar Cells*, the most often used disciplines are applied physics and electrical engineering. As *Solar Cells* is the main vehicle for disseminating research results on solar cells, we can conclude that applied physics and electrical engineering are the main disciplines contributing to research on solar cells. At a more aggregate level considering all the energy related journals as a 'macro-journal of the energy science' and combining their references, the scientific disciplines contributing most to the energy field can be identified.

In Figure 1 the main disciplines which emerge as contributors in the energy field are shown. Interdisciplinary citations (around 51% of the total) have been omitted and the intradisciplinary citations are shown as percentages of total non-interdisciplinary citations. The cutoff point was arbitrarily set at 2%. Applied physics appears to be the main contributor with more than 12% of the citations. Chemical engineering, physical chemistry and chemistry follow with 9.7%, 8.6%, and 7% respectively. On average, chemical disciplines appear to be the most important contributors to the field of energy.

As far as the sources of energy research is concerned, Table 2 provides a breakdown of the number of contributions provided by selected countries. Out of 6 075 items covered by these journals during the period under examination, 4 858 are allocated to the countries of origin. That is, the 12 countries in our sample produced 80% of the core energy related literature. By comparing Tables 1 and 2 we can further identify the specialization of different countries. For example, the majority of contributions (79%) in the journal *Solar Cells* is provided by three countries, the USA (52%), France (15%) and India (13.7%). Similarly contributions on hydrogen are provided by the USA (29%), Canada (16%), France (14%) and Japan (10%).

Table 3 provides a synoptic picture of the contributions of a variety of countries. The USA provides 53% of the energy literature with West Germany and the UK following with 10% and 8% respectively.

Among the non-industrialized countries in our sample, India provides most of the contributions (271) in the energy field with Mexico and Brazil following with 34 and 21 contributions over the period.

Of course, there is a possibility that the *SCI* database is biased against non-English speaking, say Russian or Japanese journals due to transliteration (or transcription) problems. However, it has been reported[12] that Soviet information scientists are satisfied with the coverage the *SCI* provides to the Soviet journals.

In addition, it can be argued that the promise of the *SCI* to index the most important and respective journals in each discipline has a self-fulfiling effect. Important contributions would be submitted preferentially to journals indexed by the *SCI* and therefore the *SCI* has become a representative forum of the international scientific literature.

Conclusions and policy implications

This article is an effort to outline the structure and sources of energy science. Based on the principle that the knowledge bank of any field is its published literature, the core energy journals are identified and the struc-

Table 3. Number of publications from different countries (1984–1986).

Country	No of publications	% of publications
USA	2 597	0.53
West Germany	466	0.10
UK	413	0.08
Japan	340	0.07
Canada	274	0.06
India	271	0.06
France	208	0.04
Australia	193	0.04
Sweden	35	0.01
Mexico	34	0.01
Brazil	21	–
South Africa	6	–
Total	4 858	1 00

ture and sources of published literature are delineated. Applied physics is found to be the most important among the single disciplines used in energy science while on average chemistry related disciplines (chemical engineering; physical chemistry and chemistry) are found to be prominent. The policy implications are that energy courses at Universities should emphasize chemical disciplines in their curricula; energy research institutes should employ proportionally more chemical orientated scientists (or at least those with a chemical background) and money allocated for energy research should take into consideration the fact that chemistry related disciplines currently make the most contributions to energy science.

The USA is identified as the most prominent contributor to energy science literature, providing 53% of the total contributions; West Germany and the UK follow providing 10% and 8% of the literature respectively. Among the less developed countries, India provided more than eight times the number of contributions of the second country, Mexico. South Africa despite its technological advances in the energy field – producing commercially liquid fuels from coal in the SASOL complexes, enriching uranium with the Advanced Vortex Tube Process in Valindaba, employing dry-cooling techniques for the production of electricity etc – appears as a minor contributor to energy related literature. At a less aggregated level comparisons of Tables 1 and 2 indicate the emphasis of research in different countries. Solar cell related publications appear to come mainly from the USA followed by India and France. Similarly hydrogen related contributions have their main source in the USA, Canada and West Germany.

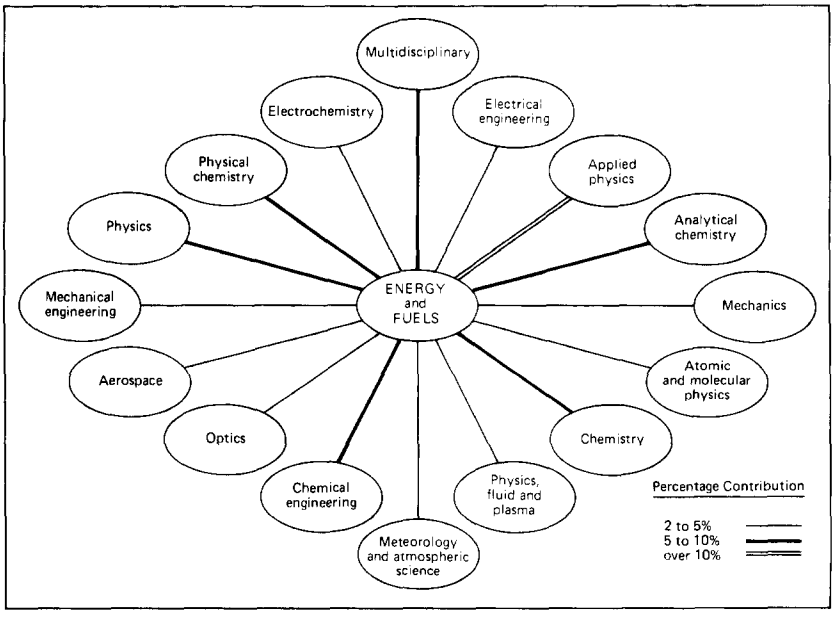

Figure 1. Scientific disciplines contributing to energy science.

Obvious implications stem from the analysis. Those interested in solar cells should include in their set of scanned countries India and France, those working on hydrogen should keep an eye on developments in Canada and West Germany.

Questions also arise concerning the performance of different countries as far as publications is concerned. Why does South Africa exhibit such a poor performance? Is it a matter of scientific censorship, a preference for product-commercialization (which does not necessarily yield publications), or a matter of weak emphasis on international publications from the research administration? Further research on the number of scientists, and expenditure on the field of energy research could reveal how efficient research administration is in different countries in spending the taxpayer's money.

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