A bibliometric assessment of energy research in South Africa

AUTHOR:
Anastassios Pouris[1]

AFFILIATION:
[1]Institute of Technological Innovation, University of Pretoria, Pretoria, South Africa

CORRESPONDENCE TO:
Anastassios Pouris

EMAIL:
apouris@icon.co.za

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The results of an effort to identify the performance of energy and fuels research in South Africa during the most recent period (2003–2013) are reported. Bibliometric approaches have been employed in order to assess the field of energy research. Energy research was identified to be improving over time, albeit from a small basis. The field appears to equally emphasise fossil and renewable energy research. Similarly, universities were identified to be producing a subcritical number of energy articles in comparison with international organisations. The relatively small activity in the energy field appears to affect the international collaboration of the field, which is well below the national average. International comparisons in terms of articles per GWH of electricity produced and articles per million population show that South Africa should increase substantially its effort in the field in order to be comparable with other countries.

Significance:

- This article makes a unique contribution in scientometrics to the field of energy research in South Africa which, given its multidisciplinary nature, is a generally neglected field of study in South Africa.

Introduction

Monitoring and assessment are integral parts of science, technology and innovation policy. Decision-makers need to know the performance of the various research disciplines so they can make intelligent decisions in the allocation of scarce resources. Historically, monitoring and assessment relied on expert opinions. Nowadays such assessments are based on quantitative information.

One of the most efficient and objective methods of assessing research and innovation performance is through bibliometric indicators. Bibliometric analysis, the quantitative study of the research system, is based mainly on publication indicators. In bibliometrics, the number of publications in a field is considered to be an indicator of research activity and the number of citations as an indicator of impact.

Bibliometric assessments have a number of advantages. For example, they are repeatable and verifiable exercises. They are not dependent on the choice of experts/peer reviewers or on their opinions which may vary. Their most important advantage is probably that they allow comparisons among different scientific disciplines and different countries. Both types of comparisons are not possible through peer-review approaches as it is almost impossible to find peers with expertise in different scientific fields and knowledge of the research systems in different countries.

Within this context, a number of South African related assessments have appeared in the open and grey literature recently.[1-3] There are limited mapping and comparative assessments in the field of energy nationally and internationally. Relevant literature includes Vlachy[4], Pouris et al.[5], Uzun[6] and Kostoff et al.[7]. As we have argued previously:

> *This lack of research activity may have a number of adverse consequences for the economy. For example, it can be argued that the lack of expertise and independent advice (e.g. in the country's universities) may be partially the cause of the recent failure of Eskom to meet electricity demand in the country.*[8(p.2)]

Similarly, the current debate related to the country's nuclear energy needs may have been better informed from independent, academic investigations.

The objective of this investigation is to assess the field of energy research in the country. More specifically, the objective is to assess the performance of the field during the most recent period from 2003 to 2013 to: (1) identify the sub-disciplines (e.g. fossil fuel research vis-a-vis renewable energies) emphasised in the country; (2) compare the country's performance with those of other countries and (3) elaborate on relevant research policy issues. These issues can guide policy in a number of domains. For example, the number of research publications produced is related to the expertise and financial resources available in the field in the country. Hence, one question that can be answered is whether the field is adequately supported. Similarly, the determination of sub-disciplines in which research is published can identify areas of inadequate support or emphasis. Comparisons of research outputs at institutional level can provide insights on the efficacy of existing instruments, approaches, etc.

Methodology

Bibliometric assessments require the availability of a database that covers adequately the subject under investigation. The Thomson Reuters databases – Science Citation Index Expanded, Social Sciences Citation Index and Arts and Humanities Citation Index – are the most often used for these types of investigations.

These databases combined cover comprehensively the most prestigious journals in the world in all fields of research and constitute a unique information platform for this objective. The most important advantage of these journals is that they constitute the most important (in terms of impact) journals in the world. Furthermore, the Thomson Reuters databases provide the corporate addresses of all co-authors in an article, and hence comprehensive coverage is possible.

In South Africa, the Department of Higher Education has approved the journals indexed by the Thomson Reuters databases for subsidy purposes; therefore universities receive approximately ZAR120 000 for each article published in one of these journals and provide incentives to their researchers to publish in such journals. Consequently, it is expected that the databases will cover not only the most important South African energy-related research but also the majority.

Two approaches were considered for the extraction of the relevant research literature: phrase-based query and journal-title-based query.

Thomson Reuters assigns the indexed journals to scientific categories. The energy-related journals are grouped under the title 'Energy and Fuels'. This group includes 138 journals. These journals can be considered as consisting of the 'core' journals of the field of energy in the Bradfordian sense.[9] It is emphasised that there are articles related to energy that are not published in the core journals. However, the most important and highest impact energy literature will be that published in the core journals, and hence this analysis aims to identify South Africa's contribution in the core energy literature. Keyword-based searches were used for the identification of research related to different types of primary energy (e.g. fossil and alternative energy; energy converters).

The platform was interrogated for the identification of South African authors publishing in the field of 'Energy and Fuels' during the period 2003–2013. The end of the period was chosen as 2013 as this was the most recent year with complete data. This investigation was initiated during 2014 and was completed during 2015.

The extracted information was analysed in order to identify trends over time; relative performance in comparison with other scientific disciplines in the country; research emphases to various primary sources of energy and technologies; prolific publishing organisations; co-authorship patterns with other countries and institutions; and relative performance vis-à-vis a set of comparator countries (i.e. Australia, Canada, New Zealand, Brazil and Russia). The comparator countries were chosen among those used for benchmarking exercises by the South African Department of Science and Technology.

Energy research in South Africa

Analysis of the core energy literature identified that 752 *articles* with at least one South African address appeared in the database during the 2003–2013 period. This figure represents 66.4% of all documents captured in the database (proceeding papers; meeting abstracts; editorial material, etc). A focus on articles prevents double counting, as a conference paper may also be published as a journal article.

Figure 1 shows the annual number of South African publications in the core energy literature for the period 2003–2013. It becomes apparent that South Africa's contribution to core energy literature is showing an increasing trend. The number of South African articles has grown from 24 during 2003 to 145 during 2013. It should be emphasised that this nominal increase takes place in an environment of increasing national research publications in general and international energy articles in particular.

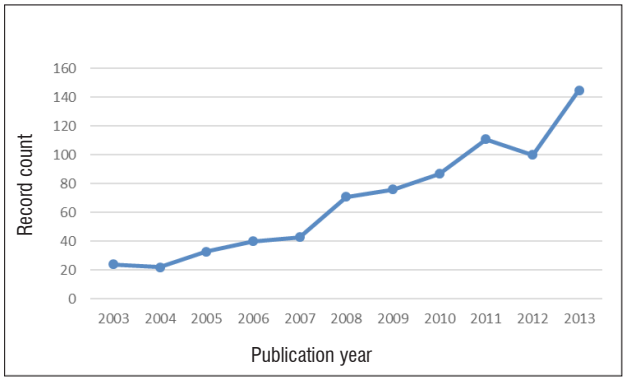

Figure 1: The number of Energy and Fuels articles from South Africa in the period 2003–2013.

Figure 2 shows the percentage of energy articles of the country's total publications. The percentage of energy articles increased faster than those of the other scientific disciplines in the country during the last decade. Energy and Fuels articles increased from about 0.6% in the beginning of the 2000s to about 1% during the end of the period. This increase is partially the result of Thomson Reuters increasing the coverage of energy journals. Figure 3 makes this point. Even though the absolute number of energy articles increased, the country's share in the world energy publications has been static since 2008.

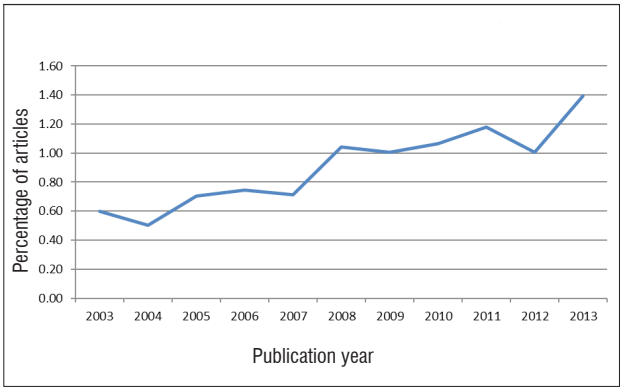

Figure 2: Percentage of energy-related articles relative to the total number of articles from South Africa in the period 2003–2013.

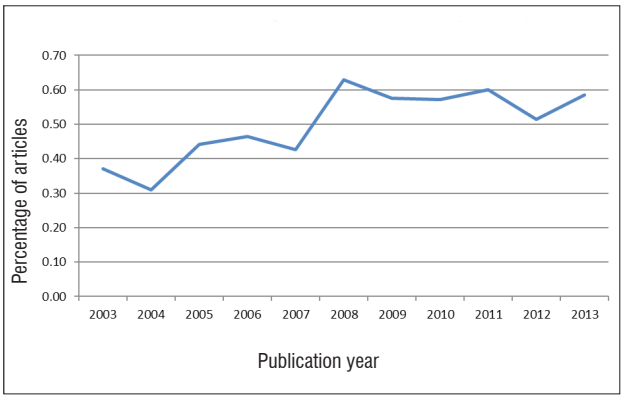

Figure 3: Percentage of energy-related articles from South Africa relative to the total number of articles in the field during the period 2003–2013.

Figure 3 shows the percentage of South African Energy and Fuels publications within the total field. The relevant share increased from about 0.4% at the beginning of the period to about 0.6% at the end of the period. However, the trend has been static since 2008.

Table 1 shows the number of articles produced by South African researchers according to various research areas during the 2003–2013 period. The table reveals a priority ranking. Environmental Sciences and Ecology and Chemistry are on top of the list with more than 5000 articles over the period. Energy and Fuels appears 47th in the list with 752 articles. It is interesting to note that Water Resources – another multidisciplinary field – appears 22nd in the list. Jacobs et al.[2] argued that the existence of a funding body like the Water Research Commission is the underlying factor for the good performance of this research area. While there is an energy-related agency in the country (Sanedi), it suffers from limited financial support by the government. Similarly, other organisations like Eskom and the National Research Foundation provide limited support for energy research. Furthermore, changes in the various national incentives (e.g. THRIP) are expected to have an adverse effect on energy research publications.

Table 1: Number of research articles from South Africa in the period 2003–2013 according to research area

Rank	Research area	Record count
1	Environmental Sciences Ecology	5326
2	Chemistry	5099
3	Engineering	4644
4	Physics	4037
5	Plant Sciences	3046
6	Mathematics	2879
7	Science Technology Other Topics	2588
8	Agriculture	2566
9	Zoology	2541
10	Public Environmental Occupational Health	2431
11	Infectious Diseases	2407
12	Astronomy Astrophysics	2108
13	Psychology	2102
14	Geology	2072
15	Business Economics	2072
16	Immunology	1998
17	Biochemistry Molecular Biology	1979
18	Material Science	1894
19	Education Educational Research	1828
20	Pharmacology Pharmacy	1812
21	General Internal Medicine	1657
22	Water Resources	1618
23	Microbiology	1596
24	Biotechnology Applied Microbiology	1581
25	Veterinary Sciences	1579
26	Marine Freshwater Biology	1545
27	Religion	1268
28	Computer Science	1213
29	Entomology	1198
30	Food Science Technology	1167
31	Virology	1121
32	Crystallography	1070
33	Evolutionary Biology	1013
34	Mining Mineral Processing	948
35	Government Law	935
36	Surgery	924
37	Biodiversity Conservation	920
38	Metallurgy Metallurgical Engineering	908
39	Neurosciences Neurology	896
40	Genetics Heredity	889

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Rank	Research area	Record count
41	Social Sciences Other Topics	877
42	Paediatrics	864
43	Respiratory System	807
44	Meteorology Atmospheric Sciences	781
45	Linguistics	760
46	Health Care Sciences Services	757
47	Energy Fuels	752
48	Life Sciences Biomedicine Other Topics	744
49	Public Administration	743
50	Psychiatry	738
51	Cardiovascular System Cardiology	732
52	Geochemistry Geophysics	699

Table 2 shows the distribution of the South African Energy and Fuels publications to different scientific specialties. Articles are allocated to categories according to the journal in which they are published. Journals are categorised by Thomson Reuters' staff and may belong to one or more categories. The distribution of articles to disciplines shows the linkages of Energy and Fuels to other research areas. Approximately 40% of Energy and Fuels articles are based on Engineering and 12% on Chemistry. In comparison with worldwide emphases in the field, South Africa pays less attention to electrochemistry (9.7% versus 17% worldwide), biotechnology (5.8% versus 9.6%) and agriculture (5.1% versus 9%).

An important component of scientometrics is the capability to identify the subfields and/or technologies constituting a research field.

Table 2: Distribution to research area of Energy and Fuels research articles from South Africa in the period 2003–2013

Research area	Record count
Energy Fuels	752
Engineering	299
Chemistry	93
Electrochemistry	73
Environmental Sciences Ecology	69
Construction Building Technology	65
Thermodynamics	57
Biotechnology Applied Microbiology	44
Agriculture	39
Physics	34
Mechanics	25
Materials Science	23
Mining Mineral Processing	9
Geology	8
Optics	7
Nuclear Science Technology	5

Research fields are composed of many subfields and technologies which are constantly developing or becoming obsolete. The identification of these emphases is of importance for policymakers who need to guide the system according to their priorities and for researchers who need to know fledgling technologies which will shape the discipline in the future. It is also critical to emphasise that the composition of the research landscape is dynamic.

Researchers working in the field develop approaches in order to extract the relevant information from bibliometric and patent databases.[7,10]

Table 3 presents the classification of the South African articles in the research area Energy and Fuels. For the fossil fuels, the keywords used were: fossil; coal; oil; gas; gasification; liquefaction; alkylation; desulfurisation; electrocatalysis; liquid fuel; fluidised bed; emission; char; ash; combustion; pyrolysis; catalysis; incineration; engine; turbine. Among the Energy and Fuels articles, 237 articles had in their titles one or more of the keywords characterising fossil fuels and energy.

Articles related to renewable energy were identified by searching in their titles for at least one of the following keywords: solar; hydrogen; wind; geo*; bio*; hydro power; photovoltaic; tidal; waste fuel; fermentation; microbial desulfurisation; biosulfurisation; thermal decomposition; biodegradation; biomass gasification; water gasification; renewable. A total of 211 articles was identified. The number of renewable energy related articles increased from a handful in the beginning of the period to approximately 30 articles per annum during the end of the period.

The keywords: fuel cell; photovoltaic; solar collector; electrode; electrolyte; and membrane were used to search for direct electric converters and 66 articles related to such research were identified.

In addition, 85 energy-related articles were published in social science journals during the 2003–2013 period (Table 3).

Table 4 shows the frequency of appearance of certain terms in the list of topics of the South African energy and fuels research articles.

The topics related to 'efficiency' have the highest number of articles in the list (177). Figure 4 shows the increase in the number of energy efficiency articles during the period. 'Coal' follows with 135 entries; 'electricity' with 119 and 'oil and liquid fuels' with 113. Among the renewable energies, 'solar' and 'hydrogen' attract the most entries (98 and 73, respectively). It should be mentioned that 'solar', 'hydrogen' and 'biomass' have the common characteristic that they are not site specific. In contrast, 'wind' and 'geothermal' are constrained to geographical areas with favourable operating environments.

Table 3: Classification into broad categories of Energy and Fuels articles from South Africa in the period 2003–2013

Category	Number of South African articles	Share of South African total
Fossil	**237**	**31.5%**
Renewable	**211**	**28.0%**
Social Sciences	**85**	**11.3%**
Direct Energy Converters	**66**	**8.7%**
Total Energy and Fuels	**752**	**100.0%**

Table 4: Number of Energy and Fuel articles from South Africa in the period 2003–2013 according to specific topics

Topic	Number of articles
Coal	135
Electricity	119
Oil or liquid fuels	113
Natural gas	19
Solar	98
Hydrogen	73
Biomas*	53
Wind	34
Hydrop*	12
Geoth*	2
Thermal insulation; lighting; double glazing; water heating; space heating	59
Efficien*	177

**indicates all forms of the word*

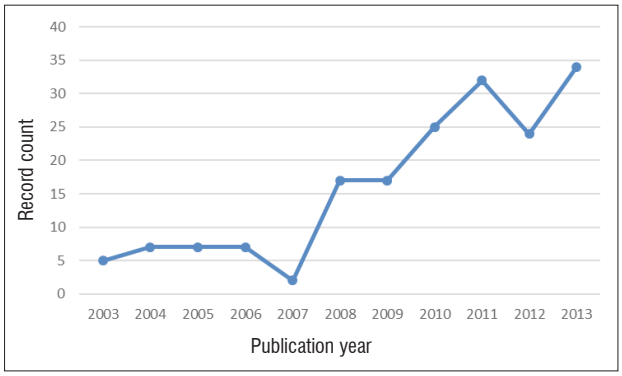

Figure 4: Growth in the number of Energy and Fuels articles related to efficiency from South Africa in the period 2003–2013.

Table 5 shows the South African organisations that are producing the majority of core energy and fuels literature. The Universities of Cape Town, Stellenbosch and Pretoria are on top of the list. Three divisions of Sasol also appear on the list. It should be noted that even the top institutions in the country produce less than 10 articles per year each on average during the period. The small number of publications makes the rankings volatile; and just a handful of publications could alter the rankings.

Table 5: South African organisations producing Energy and Fuels articles during the period 2003–2013

Organisation	Record count
University of Cape Town	107
Stellenbosch University	100
University of Pretoria	76
North West University	69
University of the Witwatersrand	66
University of KwaZulu-Natal	66
Council for Scientific and Industrial Research	59
University of the Western Cape	51
Tshwane University of Technology	46
SASOL Technology PTY LTD	27
University of Johannesburg	26
SASOL Technology RES DEV	26
Nelson Mandela Metropolitan University	24
Cape Peninsula University of Technology	19
SASOL Technology	16

The top five institutions produce more than 50% of the country's contribution to core energy and fuels literature. This result may be identified as a considerable dispersion, as a number of other scientific disciplines are concentrated in only one or two institutions in the country. For example, in the field of veterinary medicine/animal health, the University of Pretoria produces 61.68% of the country's research publications. The University of Pretoria also produces 49.15% of the country's publications in metallurgy and 46.96% in engineering mathematics.[11] As argued previously, it appears that political equity considerations in the country spill over in the research domain as well. To repeat it here, the issue is of particular developmental and research policy importance. Can a country leapfrog its science and innovation system to catch up with the rest of the world and compete internationally through a 'distributed' approach or should it concentrate its limited scientific expertise to a small number of focused research centres?

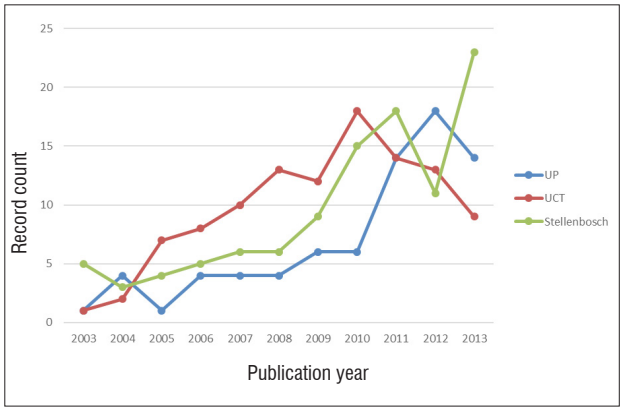

Figure 5: The number of Energy and Fuels articles produced by the Universities of Cape Town (UCT) and Pretoria (UP) and Stellenbosch University during the period 2003–2013.

Figure 5 shows the number of Energy and Fuels articles produced by the country's most prolific organisations. Again the limitation of a small number of publications should be emphasised.

Table 6 shows the number of Energy and Fuels articles produced by the most prolific organisations in India, Australia, Canada and South Africa. The South African organisations would need to increase their relevant research activity in the field fivefold in order to be comparable with those in the other countries.

Table 6: Prolific numbers of Energy and Fuels articles produced by organisations in India, Canada, Australia and South Africa during 2003–2013

Organisations	Country	Record count
India Institute of Technology	India	1560
Council of Scientific and Industrial Research India	India	1105
University of New South Wales	Australia	566
Commonwealth Scientific Industrial Research Organisation	Australia	440
University of Queensland	Australia	348
Western University of Western Ontario	Canada	575
University of Calgary	Canada	672
University of Alberta	Canada	589
University of Waterloo	Canada	435
University of Cape Town	South Africa	103
Stellenbosch University	South Africa	100
University of Pretoria	South Africa	76

Table 7: Countries collaborating with South Africa in Energy and Fuels articles

Country	Record count	% of 752
South Africa	752	
USA	59	7.846%
France	28	3.723%
People's Republic of China	25	3.324%
England	25	3.324%
Iran	20	2.660%
India	20	2.660%
Canada	18	2.397%
Nigeria	15	1.995%
Netherlands	13	1.729%
Germany	13	1.729%
Australia	13	1.729%
Malaysia	8	1.064%
Zimbabwe	6	0.798%

Table 8: Country ranking according to number of Energy and Fuels articles in 2003–2013

Rank	Country	Record count
1	People's Republic of China	33 971
2	USA	24 760
3	Japan	6280
4	Germany	6078
5	India	5721
6	Canada	5307
7	England	5120
8	South Korea	4722
9	Spain	4714
10	France	4326
11	Italy	4161
12	Australia	3579
13	Taiwan	3459
14	Iran	3127
15	Turkey	2928
16	Netherlands	2088
17	Brazil	2077
18	Sweden	1988
19	Russia	1913
20	Malaysia	1842
21	Denmark	1487
22	Norway	1341
23	Poland	1308
24	Greece	1267
25	Czech Republic	1241
26	Switzerland	1232
27	Thailand	1159
28	Mexico	1120
29	Singapore	1099
30	Portugal	1092
31	Belgium	982
32	Finland	928
33	Scotland	924
34	Saudi Arabia	793
35	**South Africa**	**752**
36	Austria	702
37	Egypt	664
38	Ireland	613
39	Algeria	547

Table 9: Comparison of the number of Energy and Fuels articles from South Africa and comparator countries in 2003–2013 according to electricity production (GWH) and population

Country	Energy articles 2003–2013	Articles/ GWH(000)	Articles/ population (million)
South Africa	752	2.9	13.9
Brazil	2078	3.7	10.2
Russia	1914	1.8	13.1
Australia	3603	14.5	152.6
Canada	5316	8.3	150
New Zealand	366	8.3	81

Table 7 shows the countries with which South African researchers collaborate for their research in the field of energy and fuels. USA, France, China and England are the top collaborating countries. It should be noted that Germany is lower down in the list (at 11th) even though it is third in collaborations with South Africa across all disciplines.[12] It should also be noted that 36.6% of the disciplinary articles were co-authored with international partners, which is lower than the country's average of 53%.[1] It can be argued that the low international collaborative activity in this field is the result of its low research activity in the country, although collaboration in the field has increased from 25% at the beginning of the period to 31% at the end of the period.

Table 8 shows the South African ranking according to the number of Energy and Fuels articles produced. South Africa is ranked 35, just above Austria and Egypt.

Table 9 shows the number of publications in the 'energy and fuels' core literature from South Africa and five comparator countries – Australia, Canada, New Zealand, Brazil and Russia – during the more recent period 2009–2013. The comparator countries are those with which South African authorities historically have compared the country.

Only New Zealand produces fewer Energy and Fuels articles than South Africa. In order to normalise the comparison, we estimated the number of energy and fuels publications per million population and per KWh of electricity produced. The two indicators provide evidence of the research that supports the population and the energy sector. Table 9 shows that South Africa compares unfavourably with the five comparator countries in terms of number of publications per KWh and it is half way in terms of articles per million population. It should be noted that South Africa is closer to Brazil and Russia and appears to be weaker than Australia and New Zealand. New Zealand appears to be stronger than South Africa in these comparisons even though it produces fewer research articles than South Africa.

Discussion and conclusion

A bibliometric assessment was undertaken of energy and fuels research in South Africa for the period 2003–2013. The major findings are summarised as follows:

- The South African national research system is producing a relatively small number of research publications in the international energy core literature. Energy research literature constitutes approximately 1% of the national output. Comparisons with the field of water research (another multidisciplinary field) support the argument that specified funding for particular research fields has the desirable effect of improving research performance.
- The number of South African energy research publications is following an increasing trend, albeit from a small basis. Furthermore, energy research is distributed across a number of universities with each organisation producing a small number of research articles. The small number of research articles can be interpreted as a small number of relevant researchers. Hence, the move of one or two prolific researchers from one institution to another could drastically change the rankings of the institutions producing energy research. Comparisons with universities abroad indicate that the South African universities should aim to increase fivefold their energy-related publications (as well as their number of researchers in the field) if they wish to be comparable with similar institutions abroad.
- The top five most prolific institutions in the country produce more than 50% of the country's contribution to core energy and fuels literature. This spread is considered a high dispersion as a number of other scientific disciplines in the country are concentrated in only one or two institutions. It is suggested that political equity considerations in the country spill over in the research domain, which is of particular developmental and science policy importance. Can a country leapfrog its science and innovation system to catch up with the rest of the world and compete internationally through a 'distributed' approach or should it concentrate its limited scientific expertise to a few focused research centres? This issue has been identified as one of the major South African policy challenges by the Organisation for Economic Cooperation and Development in their review of the country's innovation policy.[13]
- Analysis of the specialisation patterns of energy research shows that fossil and renewable energy related research are equally emphasised in the country, albeit by a small number of articles. Topics related to energy efficiency appear to be following an ascending trend.
- Identification of the country's collaborative patterns indicates that energy researchers do not collaborate to the same extent as researchers in other research areas. It is suggested that this is a result of the limited energy research in South Africa.
- International comparisons in terms of articles per GWH of electricity produced and articles per million population show that South Africa should increase substantially its effort in the field in order to be comparable with other similar countries.

Probably the most important finding for policy is the small number of research articles in the field. The discipline's ranking is far below what was expected from a research field with a dedicated agency (Sanedi). Water research, another multidisciplinary field in the country with a dedicated agency, is ranked substantially higher than energy research. The discrepancy can be linked to Sanedi's limited budget. It is also interesting to identify whether the relevant departments are using publication outputs in order to decide priorities and funding.

The lack of independent academic energy research has critical impacts for the planning of energy in the country. In the past, it has been argued[8] that the inability of Eskom to meet electricity demand could have been prevented if there were independent researchers to argue in favour of additional power capacity. Currently, the lack of expertise in the field affects the research debate related to the need of nuclear energy in the Western Cape and the investigations related to future supply and demand for electricity in the country.

Acknowledgements

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