Scientometric assessment of selected R&D priority areas in South Africa, a comparison to other BRICS countries

ABSTRACT A scientometric analysis of selected research priority areas in South Africa was done using the Web of Science database for a period 2002 - 2012. The performance of the country in the areas of biotechnology, energy, astronomy and palaeontology in terms of the publication output in these areas is compared using two classic scientometric indicators, the activity and attractivity indices. These are important priority areas as highlighted in various government policy documents and the aim was to identify if outputs in these field are corresponding with government policy. The study also identifies leading institutions in the country in terms of publication output while the performance is also benchmarked against that of the other BRIC (Brazil, Russia, India and China) group of countries as well as Egypt. It is found that the country is doing relatively well in research areas in which it enjoys geographical advantage such as astronomy and palaeontology and compares favourably with comparator countries in all areas reviewed. In terms of the institutional profile and based on publication outputs over the period considered, the University of Cape Town is a leader in biotechnology and energy, University of the Witwatersrand in palaeontology and the National Research Foundation in the area of astronomy.

KEYWORDS: activity index, attractivity index, BRICS, research priority areas, scientometrics, South Africa

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1. INTRODUCTION

Science and technology or at least scientific knowledge, as measured by the number of publications, is increasingly accepted as an important factor of economic growth (Mansfield, 1991; Narin, Hamilton & Olivastro, 1997). South Africa recognised this and so the country adopted the National Research and Development Strategy in 2002 to enable the transition from a resource-based economy to a knowledge economy (DST, 2002). Following this, a number of targeted interventions and investments in specific fields of science were made. One of the interventions was the introduction of the Biotechnology strategy (DST, 2001), after which the government, through the DST allocated R450 million between 2004 and 2007 for this initiative most of which was used to establish the biotechnology regional innovation centres (Al-bader, Frew, Essajee, Liu, Saar & Singer, 2009). The main goal of the centres was to develop commercial products in biotechnology with two of these centres located in the KwaZulu-Natal Province , one in the Western Cape and one in Gauteng Province. Therefore there is a need to understand how these are performing relative to their purpose and relative to international outputs. The purpose of this paper is to identify key trends in specific priority technical fields in South Africa and to provide a foundation for policy planning. The selected areas are evaluated and compared for research performance in an effort to provide an integrated perspective using a bibliometrics approach.

Bibliometrics has been used extensively as a quantitative measure of progress of research in specific countries (Jacobs & Ingwersen, 2004; Sooryamoorthy, 2010; Kahn, 2011; Pouris, 2009) in a selected region such as Africa or Southern Africa (Naravaez-Berthelemot, Russell, Arvanitis, Waast & Gaillard, 2002; Pouris & Pouris, 2009). Bibliometrics has also been used to measure research progress against a set of priority research areas such as the European Commission’s FP7 priority areas (Hassan, Haddawy, Kuinkel, Degelsegger & Blasy, 2012; Leydesdorff & Gauthier, 1996). South Africa has certain characteristics which make it unique. For example, recently it has been invited to the BRIC grouping of countries, yet it has a number of developmental challenges. In terms of scientific output, it is well recognised that South Africa is a leading producer of research output in Africa, as measured by the total number of publications. However, it is worth noting that it has set itself a number of priority areas, as articulated in the country's National R&D Strategy (DST, 2002) and the Ten Year Innovation Plan (DST, 2007) as well as a number of discipline-specific strategies and frameworks. The important areas further emphasised through discipline-specific strategies considered in this study are the National Biotechnology Strategy (DST, 2001), as well as the Palaeosciences Strategy (DST, 2012). These relate to a response to special social challenges or as areas that offer opportunity based on the country's strengths and/or geographical advantage. Such priority areas are viewed as central to the achievement of national goals, including enhanced economic growth, industrial competitiveness, as well as social and developmental aspirations (Kaplan, 2004). The aim of this study, therefore, is to focus on two areas that relate to enhancement of industrial competitiveness (energy and biotechnology) and the two other areas that are based on geographical advantage (astronomy and palaeontology). It is hoped that this will add to the literature demonstrating the use of bibliometrics specifically the use of indeces for comparison and measuring scientific progress.

Looking briefly at the focus areas, biotechnology has received a lot of attention because it has many potential uses and significant commercial benefits in areas such as provision of health products, alternative fuels and improving food production. In 2001 South Africa launched the Biotechnology Strategy which was aimed at initiating the development of technologies and associated products and services to address the vital science-based innovation needs of the country in the health, industrial and agricultural sectors of the economy. The government further launched a Bioeconomy Strategy in 2013 which was broader in scope focusing on agricultural, health, industry and environmental sector of the economy. These are the main policy drivers of the biotechnology investments by the government in the country. South Africa has been interested in alternative energy for a while, for example the Department of Energy (which was then a Department of Minerals and Energy) published a biofuels strategy (2007) through which it encouraged production of biodiesel and bioethanol for inclusion in automotive fuels, through fuel levy exemptions. Also the White Paper on Energy Policy (1998) acknowledged the importance of alternative energy and a diverse energy supply. Additionally, South Africa has an energy-intensive economy with most of the primary energy derived from coal. As a result, the country has high emissions of greenhouse gasses per capita. In fact, in some cases it is higher than some European countries; as a result energy efficiency and development of alternative energy is an important focus for the country

(Winkler, 2007). Moving on to astronomy, South Africa has developed the infrastructure to enable astronomy and space physics research investing in facilities such as the Hartebeesthoek Radio Astronomy Observatory for radio astronomy and space geodesy, the Hermanus Magnetic Observatory for geomagnetism and space physics as well as a facility in Antarctica (Martinez, 2008). Martinez (2008) further notes that it is due to these investments that the country has been able to attract big international projects in astronomy, such as the Square Kilometre Array (SKA). Investments include the MeerKAT radio telescope based in the Northern Cape and its predecessor the seven-dish Karoo Array Telescope (KAT-7) the MeerKat will be integrated into the SKA on its completion. Another investment in this field includes the establishment of the Southern African Large Telescope (SALT) which is the largest single optical telescope in the southern hemisphere and among the largest in the world. In terms of palaeontology and astronomy, these fields are well recognised for their ability to attract the attention of young children to science, in particular due to their ability to "capture popular imagination" (DST, 2012). In addition, these fields are further emphasised due to the country's geographical advantage; South Africa has some of the best evidence in the world of how plant and animal life has developed. Therefore, it became critical that the country invests in developing the human capital to protect the fossil heritage and build expertise in palaeosciences.

The Department of Science and Technology (DST) is the government ministry responsible for development of policies as well as government intervention in science and technology in South Africa. The government additionally has science councils that conduct research in specific areas according to their mandates. There are numerous research councils; some are sector-specific, concentrating on a specific sector such as agriculture, water, mining or medical research. One that conducts generalised industrial research is the Council for Scientific and Industrial Research (CSIR), which falls under the responsibility of the DST and tends to focus on the areas that are regarded as important according to government policy. In addition, there are also funding agencies that provide for research. A prime example of such a funding agency is the National Research Foundation (NRF), which funds early stage research mostly at universities. The NRF additionally houses national facilities that conduct research in their own right. These include the iThemba LABS that conduct nuclear research, particularly nuclear medicine and the South African Astronomical Observatory (SAAO), which is a national facility for astronomy. In addition to these, there are currently 23 established public universities in South Africa that conduct research with varying emphases, in addition to their teaching responsibilities. The most prominent of these in terms of the world rankings are the University of Cape Town, University of Witwatersrand, University of Pretoria, Stellenbosch University and University of KwaZulu-Natal (Matthews, 2012).

Publications indexed in the Science Citation Index (SCI) databases as provided by Thomson's Reuters Incites^{TM} platform are used (2012). The aim was to establish developments in the identified research areas as to whether South African research outputs are aligned with the S&T strategic objectives of the country. The research focus of the paper was on application of existing tools and scientometric indicators in the South African context. The research aims to provide some answers to the following two related questions:

- What is the current status of South African research outputs of the selected science and technology priority area? What is the level of output in these fields, and what is their stage of development? To answer this, the research considered the publication profile, citation profile as well as institutional profile for each of the fields.
- What is South African performance relative to other countries? The performance of South Africa is compared with BRIC countries and also includes a comparison with one African country; the country selected was Egypt as it is the second most productive country in Africa in terms of publications.

The BRICS have previously been studied by a number of authors to compare performance of countries within the group. Some studies have considered the scientific outputs (Bornmann, Wagner, & Leydesdorff, 2015), collaboration within the grouping (Finardi, 2015), and the comparison with other country groupings (Yi, Qi, & Wu, 2013). Additionally, studies where countries in the same grouping are compared are common practice; for example, studies have been done looking at the Organisation for Economic Co-operation and Development (OECD), EU27 and Association of South East Asian (ASEAN) countries. The reason for the choice of the BRICS in this context is that South Africa belongs to the grouping and BRICS countries have been working towards closer cooperation between the members, within the scientific disciplines specifically. It must be pointed out that the focus of this paper is on the performance of South Africa in its priority areas, while the other BRIC countries are used for comparative purposes only.

Considering previous work, Bornmann et al. (2015) found that the BRICS countries, with the exception of Russia, have increased their output in terms of most frequently cited papers at a higher rate than the top-cited countries worldwide. While that study did not have a specific focus on the areas as considered here, their analysis is in line with the findings presented in this paper. Yi *et al.* (2013) compared the performance from a scientometrics perspective of the BRIC (Brazil, Russia, India and China) and CIVETS (Colombia, Indonesia, Vietnam, Egypt, Turkey and South Africa) groups, which are both viewed as promising emerging economies. Using some knowledge-based economy indexes, such as knowledge economy index, and some scientometric indicators, such as disciplinary specialisation index, the authors found that that there was no significant difference between CIVETS and BRIC in knowledge-based economy performance, scientific research quality and scientific research structure. Finardi (2015) also conducted a study on the scientific collaboration between the BRICS countries, emphasising that these countries have discussions on scientific and technological collaboration as part of their summits.

In the following section we will discuss the theoretical background for some of the indicators used, followed by the methodology section, after which the article focuses on the results and discussion and, lastly, the conclusions.

2. BIBLIOMETRIC INDICATORS

In this section, an overview is given of important concepts such as bibliometrics, the use of activity and attractivity indices and the relevant scientometric measures.

Scientometrics is the science of understanding quantitative aspects of science research. In practice, scientometrics is often done using bibliometrics, described as a quantitative study of written output of science (Van Raan, 1997) and is used widely to understand the publication profile of different scientific disciplines and measure the impact of (scientific) publications. Bibliometrics is sometimes referred to as the evaluation of science through bibliographic statistics; the earliest definition which is widely accepted is by Pritchard (1969), which defines bibliometrics as the application of mathematics and statistical methods to books and other media of communication. When measuring the performance of a scientific system, it is important to consider that there are input indicators and output indicators. Publications are output indicators especially for basic and applied science (Wagner-Döbler, 2005). This is important as the use of an inappropriate indicator will give results of no practical significance. Another aspect to consider is normalisation. Normalisation is a necessity especially in cases where different disciplines are compared, since communication behaviours differ considerably among various subject fields (Glänzel & Moed, 2013). An additional but very important issue is the unit of analysis when it comes to publications as they can be various alternatives where the publication is authored by more than one researcher or researchers from more than one institution or country. There are three widely accepted counting methods namely, whole counting, fractional counting, and first author counting (Larsen, 2008). According to Larsen 2008, in whole counting, all unique countries, institutions or authors contributing to a publication receive one credit.

Leydesdorff and Gauthier (1996), while assessing the performance of the countries that have advanced materials and biotechnology as priority areas, expressed some concerns that various countries tend to make similar choices in terms of priority areas. According to Leydesdorff and Gauthier (1996) this is especially common amongst the OECD countries. Another problem identified in scientometric research is the classification and delineation of fields, for example the definition of biotechnology differs slightly between different regions, including which areas it encompasses. The authors further state that delineation using core journals as done by the Thomsons Reuters Web of Knowledge classification (WoK) may not account for research published in multidisciplinary journals. Delineation is achieved by using keywords to extract the relevant publications from the database; another technique is content analysis or using only core journals.

It has been mentioned that bibliometrics analysis will be performed on the data obtained from a citation index database. Garfield (1964), the founder of the Science Citation Index (SCI), defines a citation index as an ordered list of cited articles, each of which is accompanied by a list of citing articles. The most commonly used academic citation index used in bibliometrics research is the Thomsons Reuters Web of Science™ (WoS), formally Institute of Scientific Information. It must be noted that this citation index does not cover a majority of journals but relies on selected prominent journals and on cumulative advantage distribution as described by the Bradford's law of journal use, the Lokta law of distribution and the Pareto principle of income distribution (Price, 1976). A simplified interpretation of the cumulative distribution model is that the most important literature for any subject field is likely to be found in a small collection of publications.

As mentioned earlier, bibliometric indicators have been used extensively to measure the performance of research output in different fields, including evaluation of institutions, research area, countries and regions. Publication and citation counts provide a simple tool for determining research activity in a field within a country such as South Africa, in this case. However, in cases where the study involves different subject fields, comparison of number of publications across different scientific disciplines may be misleading, as different disciplines have different publication patterns. A useful indicator may be South Africa's share in the particular discipline or the activity index. The activity index takes into account the size of the country's science system. It was used first by Frame (1977) and is considered to be one of the classic scientometric indicators. This indicator is related to the revealed comparative advantage index which measures specialisation in economics as described by Basala (1965). It has been used previously to measure the performance across different subject fields or countries (Frame, 1977; Schubert & Braun, 1986). Pouris (2010) used the activity index in comparing the science output in Southern Africa Development Community countries.

The activity index according to Frame (1977) is the ratio of the country's share in the publication output in the field to the country's share in the world's publication outputs in all fields. According to Schubert and Braun (1986), it is the ratio of the given field's share in the country's publication output to the given field's share in the world's publication output. Another important measure is the attractivity index which, according to Schubert and Braun (1986), is defined as the ratio of country's share in citation attracted by publications in a given country's share in citations attracted by publications in all science fields. This will then also allow for a comparison of relative impact of different scientific fields. The WoS and InCites™ analytical tools do not report the activity or the attractivity indices directly, but these can be calculated from the other statistics reported.

The activity index (AI) indicates the country's relative share in world publications in a particular field of science to the overall share in world total publications as described by Frame (1977) and extended by Schubert and Braun (1986). Attractivity index (AAI) as described by Braun, Bujdoso and Schubert (1986) characterises the relative impact of the country's publication in a given subject field as reflected by the citations they attract.

3. METHODOLOGY

In this paper we use the WoK classification system, which is based on core journals classification. The research priority areas as well as WoK fields used for the classification of the publications are presented in Table 1. The table also refers to the applicable reference within South Africa where the field is classified as a priority.

Table 1. List of priority areas that are considered in this study.

Priority area	**Web of knowledge classification**	**Reference Government Policy**
Biotechnology	Biochemistry and Molecular Biology	Biotechnology strategy 2001
Energy	Energy & Fuels	RSA R&D Strategy 2002
Astronomy	Astronomy & Astrophysics	RSA R&D Strategy 2002
Palaeosciences	Palaeontology	Palaeosciences Strategy 2012

Data were collected on publications in these scientific research areas for eleven years starting in 2002. The year 2002 coincides with the launch of the South African R&D Strategy. The SCI database offered by WoS and Incites^{TM} were used exclusively for the search of journal publications to ensure that there is consistency in comparison. The advantage of this database is that it provides a comprehensive coverage of the most important and influential journals and core literature internationally. According to the Thomsons Reuters website, its collection covers nearly 25,000 international and regional journals, essays and book series in every area of the natural sciences, social sciences, and arts and humanities. The advantage of Incite^{TM} is that it enables the user to evaluate institutional or country productivity and benchmark output against peers worldwide.

In terms of energy publications listed under the 87 energy and fuels journals we used, Kajikawa, Yoshikawa, Takeda, and Matsushima (2008) followed a similar approach in their study. For astronomy there is a relative consensus that the 60 publications in the Web of Knowledge listed under astronomy and astrophysics are representative of the core literature in this field. This methodology has been followed by Bilir, Onal, Ozturkmen, and Yontan (2013) in their study of research performance of Turkish astronomers. Palaeontology is one of the smallest research areas covered by WoS (Racki, 1997). However, while WoS does not cover the majority of journals, the most prestigious or the core ones are covered (Racki, 1997; Racki & Balinski, 1999). The 52 journals indexed under the Palaeontology WoK class are expected to be sufficiently representative of the core literature in this field, and these were used for the study. For the biotechnology publications also a simple methodology was followed by extracting publications under the biochemistry and molecular biology classification this method has been used by others authors (Martinez, Jaime & Camacho, 2014). According to Abramo *et al.* (2012), the appropriate duration of citation time should be at least three years in order to provide reliable citation data. And for this reason the study was limited to a period of up to 2012 otherwise the attractivity index would not have been reliable. In this study, only articles were considered and other publication types such as book chapters and proceedings were excluded. Whole counting is used throughout this article as explained earlier. Therefore, there is a reasonable certainty that the results represent a realistic picture of all the research areas studied.

In this study, the research performance of South Africa was compared with BRIC countries and also includes a comparison with Egypt, which is the second most productive country in the African continent after South Africa (Naravaez-Berthelemot, Russell, Arvanitis, Waast, & Gaillard, 2002; Pouris & Pouris, 2009; African innovation outlook, 2014). For comparison of the research areas between different countries, cumulative data between 2002 and 2012 are used, and for comparison of research areas within South Africa data for the individual years from 2002 to 2012 are used. The comparison is made by computing the activity and attractivity indices for the selected fields in different countries in addition to the usual indicators such as publication and citation counts.

4. RESULTS AND DISCUSSION

In this section, the results of the scientometric study are presented together with the use of suitable indicators such as number of publications, citation and world share. Additionally, we use the activity and the attractivity indices.

4.1 Some primary data about South Africa and the selected countries

Table 2. Selected primary data cumulative from 2002 - 2012

Country	Web of Science Documents	Impact Relative To World	% Documents in World	% Documents Cited Relative to World
Brazil	271 332	0.61	2.32	0.91
Mainland China	1 124 872	0.63	9.60	0.92
Egypt	47 100	0.50	0.40	0.90
India	364 681	0.59	3.11	0.91
Russia	293 457	0.49	2.50	0.79
South Africa	71 233	0.79	0.61	0.94

Table 2 shows that from the selected countries, China is the biggest contributor of scientific publications.

Table 3. Number of publications in the selected fields in selected countries from 2002 - 2012

Country	Biotechnology	Palaeontology	Energy	Astronomy
Mainland China	46342	1465	18079	10721
Brazil	15895	478	2 102	4 624
India	11105	341	5 335	6 410
Egypt	1455	163	801	308
Russia	10971	2 056	2 953	12 422
South Africa	1798	283	629	1 887

The results show that among the BRICS, China is a leading producer of publications in the areas of biotechnology and energy. Russia is a leading producer of publications in astronomy and palaeontology, with China not far behind in both fields. It is interesting to note that Egypt is producing more publications than South Africa in energy research.

4.2 Comparison of the research areas within South Africa

The chart below depicts the number of publications produced in the different areas from 2002 ending in 2012.

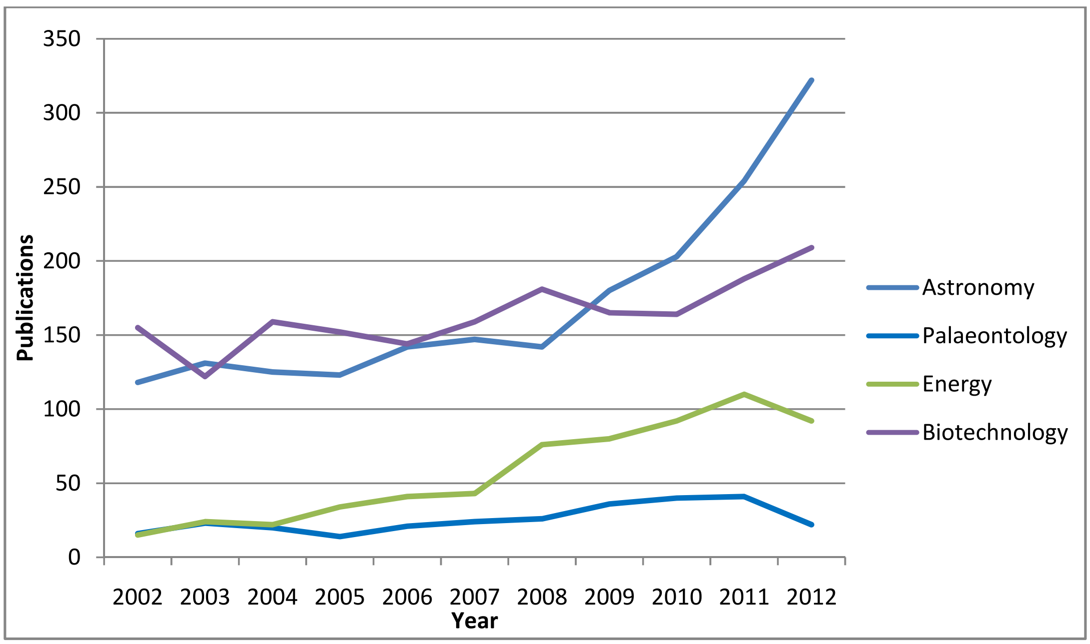

Figure 1. The number of publications in different research areas in South Africa

The above results indicate that in terms of publications, biotechnology and astronomy are experiencing a growth in terms of the number publications. The country's Biotechnology Strategy was launched in 2001 with accompanying government financial support, a few years before this increase. The growth in publications in these areas can also be attributed to a general increase in publication in South Africa. Kahn (2011) found that the high publication rate in South Africa can be attributed to the fact that the Web of Science indexes more South

African journals, and there has also been an increase in co-publication with foreign authors. According to Pouris (2012) the other main reason was the growth in the new funding framework (NFF) for higher education institutions, which provides a cash incentive of more than R100 000 to the universities for each publication that their staff produces.

Table 4. The number of publications for different fields in South Africa from 2002- 2012

Year	Country Totals	Biotechnology	Energy	Palaeontology	Astronomy
2002	4 215	155	15	16	118
2003	4 178	122	24	23	131
2004	4 526	159	22	20	125
2005	4 807	152	34	14	123
2006	5 453	144	41	21	142
2007	6 118	159	43	24	147
2008	6 952	181	76	26	142
2009	7 672	165	80	36	180
2010	8 147	164	92	40	203
2011	9,423	188	110	41	254
2012	9 149	209	92	22	322

Table 4 shows the number of publications produced in each field per year since 2002. All the areas have grown since 2002, except for palaeontology in which the growth is not of much significance. Biotechnology, energy and palaeontology grew from a very low base, while the country already had a respectable output in astronomy in 2002. The overall number of publications increased from 4215 in 2002 to 9149 in 2012, a 117% growth. Looking at the focus areas it is observed that palaeontology increased by 37% while astronomy grew by 172%. The different between these two areas in quite glaring and may point to the resources that the government has been dedicating to astronomy in an effort to attract the SKA project to South Africa. Looking at biotechnology the growth was only 34% of the 10 year period while the growth in energy was 513 admittedly from a low base of just 15 publications in

2002. Energy, especially renewable energy is an important area of research as researchers attempt to find sustainable alternative to fossil fuels that environment. Clearly the growth in biotechnology is low and inconsistent with the level of funding that has been committed to it. However, it is important to note that this funding went to the biotechnology regional innovation centres with a mandate to commercialisation, it is therefore possible that research which produce publications may have been overlooked.

In the tables that follow, a comparison of different areas in South Africa is made using the activity indices and the attractivity indices which are tracked over a period of time. The activity index was calculated from the statistics available from the citation report as obtained from WoS. The statistics used are *% documents in the field* divided by the *% documents in the world* for that particular field. As an example for South Africa, these values were 0.56 and 0.61 respectively over the period 2002-2012, giving an activity index of 0.92. In the case of attractivity, index *% documents cited relative to subject area* is divided by the *% documents cited relative to the world*.

Table 5. Activity indices of the different fields in South Africa from 2002 - 2012

Year	Biotechnology	Energy	Palaeontology	Astronomy
2002	0.99	0.55	1.84	1.70
2003	0.99	0.92	2.66	1.89
2004	0.99	0.76	2.07	1.65
2005	0.99	1.06	1.44	1.64
2006	0.99	0.95	1.82	1.71
2007	0.97	0.79	1.83	1.68
2008	0.96	1.14	1.76	1.45
2009	0.94	0.98	2.28	1.67
2010	0.96	0.95	2.40	1.85
2011	0.92	0.85	2.19	2.00
2012	1.01	0.73	1.29	2.51

In terms of astronomy and palaeontology, South Africa is clearly producing significantly high output and seemingly produces roughly double the expected from its scientific size in these fields. In terms of energy, the output is less predictable than in 2002 where the activity index is 0.55; this went as high as 1.14 in 2008 and then down to 0.73 in 2012. The activity index is close to 1 for all the years under consideration indicating that biotechnology emphasis in the country is equivalent to other areas.

Table 6. The citation counts for the different areas in South Africa from 2002 - 2012

Year	Country Totals	Biotechnology	Energy	Palaeontology	Astronomy
2002	66974	2195	128	268	2419
2003	69910	2793	219	360	2424
2004	76999	1443	251	314	2789
2005	77708	3448	584	249	3016
2006	76594	1611	495	207	5065
2007	66827	2135	377	266	2798
2008	67871	1346	606	170	4443
2009	54932	1466	566	195	4151
2010	42808	1157	484	136	2897
2011	23463	381	230	61	1730
2012	5755	53	33	8	604

Table 6 shows the number of citation received by publications in the four areas under consideration in South Africa. Looking at this table biotechnology and astronomy received higher citation counts compared to energy and palaeontology. However, this does not necessarily mean that the biotechnology and astronomy are doing any better than energy and palaeontology as different fields differ substantially in their publication patterns. This serves to illustrate the difficulty in comparing different research areas with deferent publication patterns and hence the use of the attractivity index.

Table 7. Attractivity indices of the different fields in South Africa from 2002 - 2012

Year	Biotechnology	Energy	Palaeontology	Astronomy
2002	1.03	0.93	1.11	1.01
2003	1.01	1.11	1.11	1.04
2004	1.03	1.09	1.10	1.08
2005	0.99	1.07	1.08	1.00
2006	1.04	1.07	1.10	1.01
2007	1.05	1.02	1.07	1.09
2008	1.04	0.97	1.02	1.10
2009	1.02	1.01	1.14	1.08
2010	0.95	0.94	0.96	1.06
2011	0.88	0.95	1.27	1.18
2012	0.74	0.74	0.84	1.24

Astronomy and palaeontology showed high activity index, and it can be deduced that South Africa produced roughly double the expected from its scientific size in these areas. The attractivity index for biotechnology is close to 1 for all the years under consideration except for 2011 and 2012 [Table 7]. Abramo, D'Angelo, and Cicero (2012) recommends a period of at least three years for more realistic citation data, so the results for 2011 and 2012 are consistent with this recommendation indicating a time lag between a period when an article is published to when it gets cited.

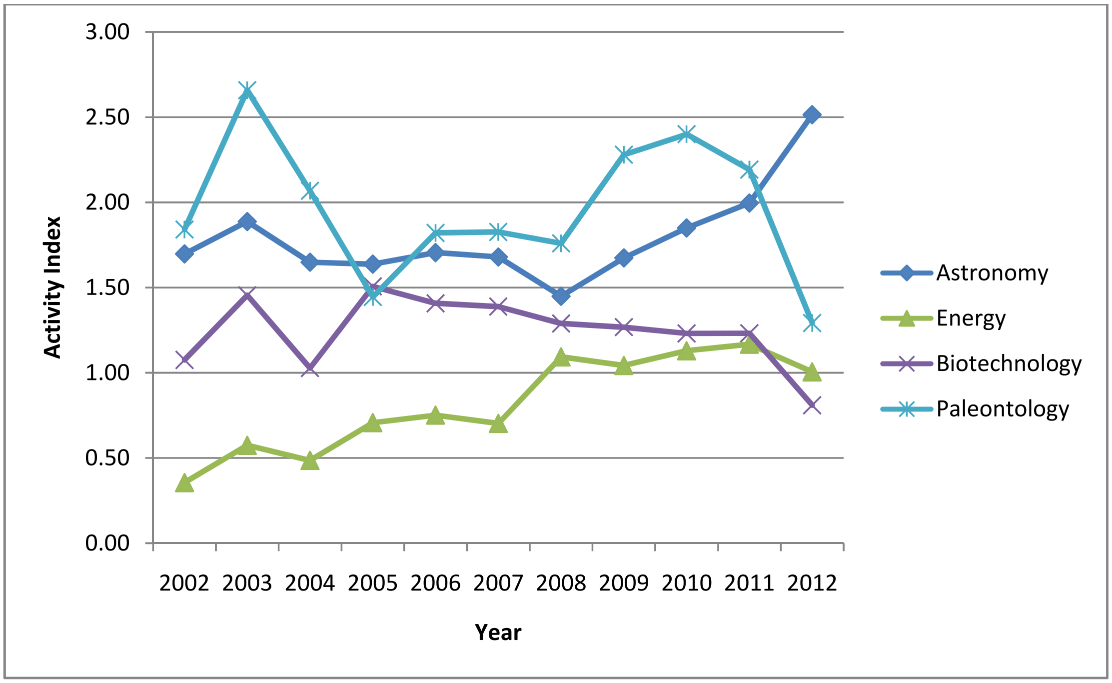

Figure 2. The activity indices of publications in priority research areas in South Africa from 2002 – 2012

The results in Figure 2 indicate that astronomy and palaeontology have high activity indices, indicating that South Africa produces roughly double the expected from the country's scientific size. This high activity index is mostly related to its geographical location; a high number of fossils have been found in the country, making it a focus for palaeontology-related research. In terms of astronomy, the clear night skies have made South Africa ideal for astronomy. South Africa developed the infrastructure to enable astronomy and space physics research, establishing facilities such as the Hartebeesthoek Radio Astronomy Observatory for radio astronomy and space geodesy, the Hermanus Magnetic Observatory for geomagnetism and space physics as well as a facility in Antarctica (Martinez, 2008). Martinez (2008) further notes that due to these investments the country has been able to attract big international projects in astronomy, such as the Square Kilometre Array (SKA). Energy has shown steady growth, surpassing the benchmark of 1 in 2008, and indicative that the efforts and resources dedicated to this field are yielding some results.

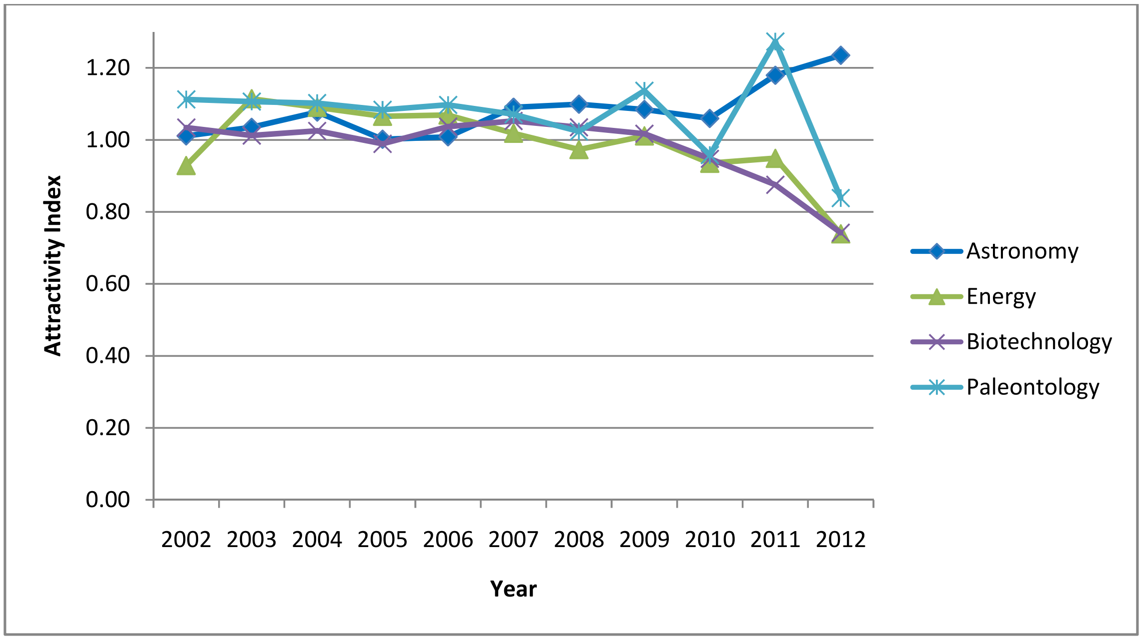

Figure 3. The attractivity indices of publications in different research areas in South Africa from 2002 - 2012

The above results indicate that the attractivity indices of all fields display quite similar trends in terms of scientific impact and relative citations.

4.3 Institutional profile of the research output in South Africa

This section gives an overview of the institutional profile for the four selected research areas. It gives a representation of the institutions that published the most in the selected areas in South Africa during the selected period of consideration.

Table 8. Institutional profile of different areas in South Africa cumulative from 2002 -2012

Research Area	Web of Science Documents	Leading institution (no. of documents)
Astronomy	1 887	NRF(744)
Energy	629	UCT (99)
Biotechnology	1798	UCT (485)
Palaeontology	283	WITS (104)

The National Research Foundation (NRF), which manages the "National Facilities", accounted for 39% in the astronomy and astrophysics research output, followed closely by University of Cape Town (UCT) at 28%. The National Research Facilities under the NRF include the South African Astronomical Observatory (SAAO) and the Hartebeesthoek Radio Astronomy Observatory. The presence of the NRF as the most productive research institution in Astronomy can be directly attributed to the government investments in these facilities.

UCT accounted for 16% in the field of energy, closely followed by Stellenbosch University (SUN) at 12%. Both institutions have seen energy as an important field of study and have established research centres in this field; namely the Energy Research Centre at UCT and the Centre for Renewable and Sustainable Energy Studies at Stellenbosch University. The Energy Research Centre at UCT is also responsible for publishing the Journal of Energy in Southern Africa, which is an ISI accredited journal.

UCT is a leading organisation in biotechnology with a share of 25.5%, followed by the Stellenbosch University which has a share of 19.2%. These organisations are ranked as leading universities in South Africa in terms of research output so this is line with the findings (Matthews, 2012).

Palaeontology is a relatively small field, with a few active researchers and few publications produced annually in comparison with the other research areas. Wits University produced 36% of all publications in palaeontology, followed by UCT at 17%. It is clear that Wits University placed a high priority in this area, as Bernard Price Institute for Paleontological Research and the Institute of Human Evolution are both based at this institution.

4.4 Comparison of South Africa with other countries

In this section, the activity and attractivity indices of the different countries are given for the priority fields. The comparison of research outputs with other countries is made using the activity indices and the attractivity indices for the countries using cumulative data between 2002 and 2012.

Table 9. Activity indices of different areas in different countries cumulative from 2002-2012

Country	**Biotechnology**	**Palaeontology**	**Energy**	**Astronomy**
Mainland China	1.13	0.64	1.67	0.65
Brazil	0.99	0.87	0.81	1.17
India	1.62	0.46	1.52	1.20
Russia	0.40	3.44	1.04	2.89
South Africa	1.23	1.95	0.92	1.81
Egypt	0.30	1.65	1.02	0.45

The results indicate that mainland China and India are paying particular attention in the biotechnology research area; this is also true for energy research. This is not surprising as biotechnology and energy feature prominently in China's 12th five year plan. Russia and Egypt have low activity indices in the field of biotechnology indicating that these countries place less priority in these areas which may not be intentional necessarily. Russia, followed by South Africa, leads in the areas of palaeontology and astronomy, with India having the lowest activity index in palaeontology and China in astronomy. The prominence of Russia in astronomy has been highlighted previously by Basu and Lewison (2005).

Table 10. The citation counts for the selected areas in different countries from 2002 - 2012

Country	**Country Totals**	**Biotechnology**	**Energy**	**Palaeontology**	**Astronomy**
Mainland China	8022500	181062	141814	11697	120187
Brazil	1852805	41796	18842	2959	56622
India	2407567	92790	58793	1828	73542
Egypt	267867	1761	4143	729	2329
Russia	1625920	18630	8610	7041	136795
South Africa	629841	18028	3973	2234	32336

Table 10 shows the number of citation received by publications in the four areas under consideration. The data is cumulative from 2002 to 2012. This serves to illustrate the difficulty in comparing different countries of different scientific size and hence the use of the attractivity index. Otherwise the biggest country with a higher GERD and human capital will appear to be doing well at first glance.

Table 11. Attractivity indices of different areas in selected countries cumulative from 2002-2012

Country	Biotechnology	Palaeontology	Energy	Astronomy
Mainland China	0.99	1.12	1.05	1.03
Brazil	1.04	1.00	1.13	1.07
India	0.97	1.01	1.14	1.03
Russia	1.11	1.01	0.83	1.15
South Africa	1.03	1.11	1.01	1.08
Egypt	1.01	0.97	1.02	0.91

It is interesting that while there is a vast difference between the different countries in terms of publication output, the attractivity index reveals a totally different scenario. The countries on average show an attractivity of close to 1 in the areas of palaeontology, energy and astronomy, meaning that the output, while varying, has comparable impact. All BRICS countries show attractivity index showing that relative to citation in biotechnology is on same level with other field. While the activity index for Egypt and Russia is low in this field the impact of the papers produced is of good quality.

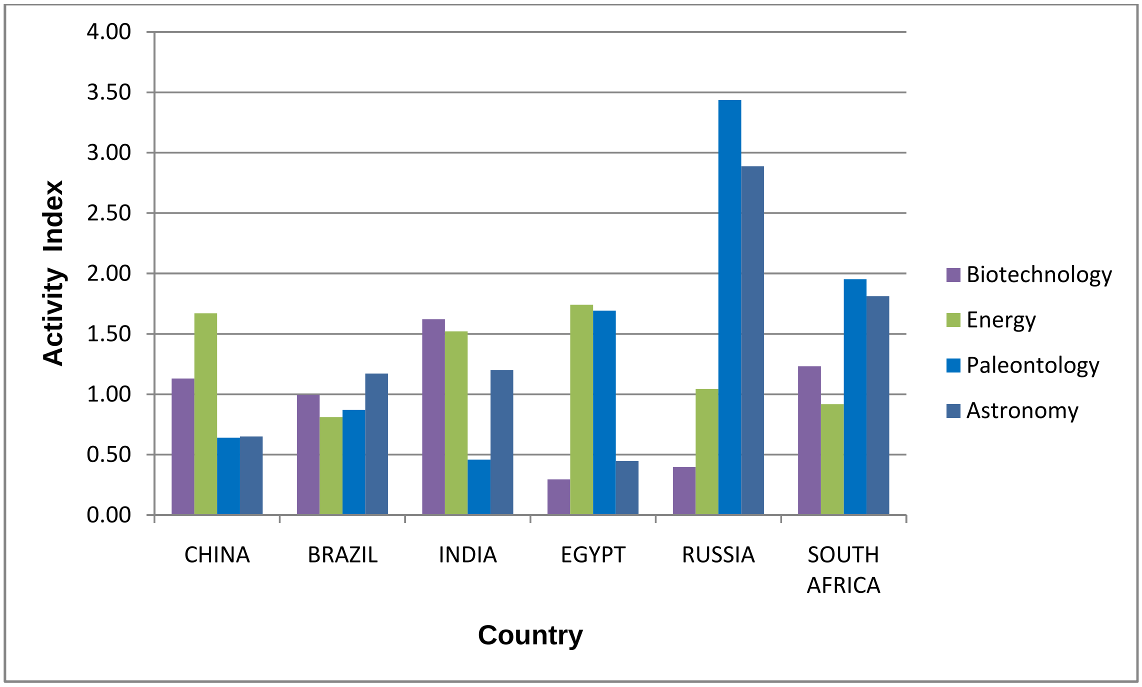

Figure 4. The activity indices of the research publications in different areas per country cumulative from 2002 - 2012

South Africa, despite its modest size, compares quite favourably with the other members of the BRIC grouping of countries of which it is now a member. It is clear that each of the countries has particular strengths. Russia, for example, places strong focus on astronomy and palaeontology. The emphasis on astronomy is most likely related to the country's historical development in this field. Interestingly, Mainland China has placed strong bias towards energy and biotechnology, which is not surprising as this country has a strong focus on these areas. China also gives high priority to both energy and biotechnology as manifested by the number of programmes and government policies; they both feature explicitly in the country's 12th Five Year Plan. To further support this, the Chinese government established of the National Energy Commission (NEC), an inter-ministerial body responsible for overseeing energy development plans (Liping, 2011).

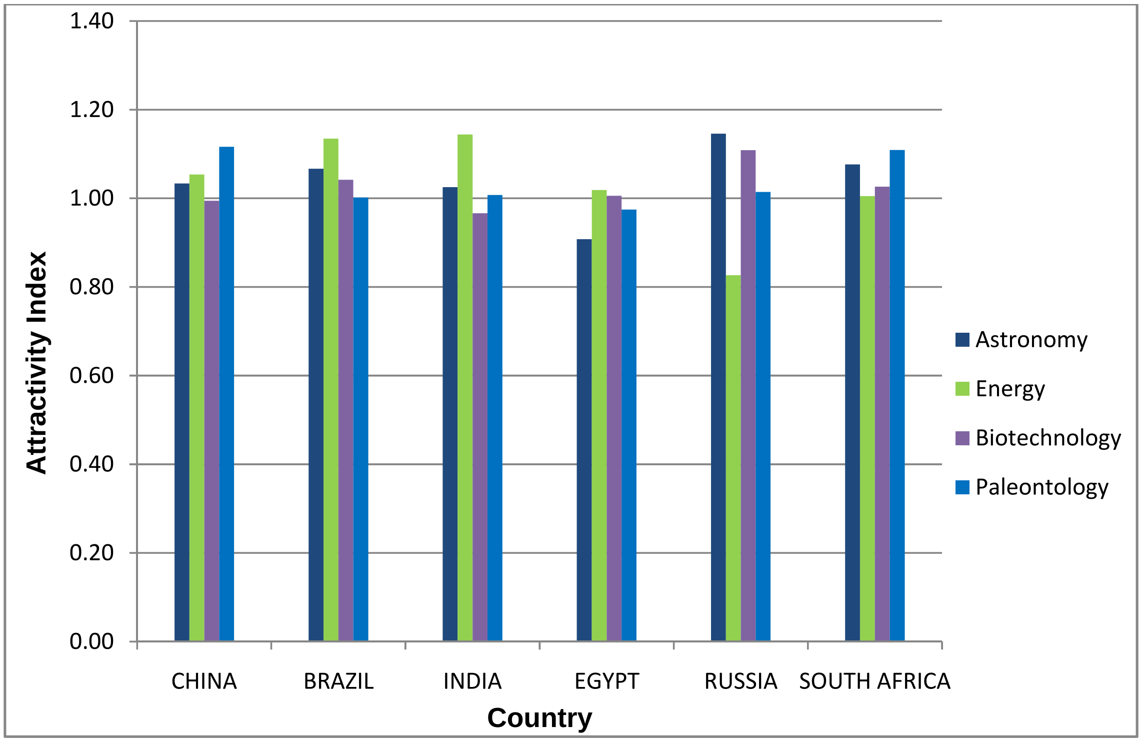

Figure 5. The attractivity indices of the research publications in different areas per country cumulative from 2002 to 2012

Figure 5 shows that in the areas of biotechnology, energy, palaeontology and astronomy the attractivity index of South Africa is comparable to that of its peers in the BRICS group, demonstrating that the quality of publications based on citations in these areas is relatively good. However, South Africa as newest member of the BRICS countries needs to leverage its position and consider increasing collaboration with the other BRIC countries in biotechnology and energy research. Joint research programmes with a country like China which has achieved a high level of output in these areas will be very beneficial. This collaboration with the BRIC countries should not be at the expense of the existing partnerships with other countries with which South Africa already has established programmes. A study by Finardi (2015) showed particular trends emerging in the collaborations between particular members of this grouping showing strongest collaboration between South Africa and India. The authors attribute this to the fact that both countries belong to Commonwealth, were part of the British Empire and share English as one of the official languages. China and Russia also showed strong collaboration which was attributed to the presence of a Socialist State structure in both countries.

5. Conclusion

The study considered a selected number of research priority areas in South Africa. The research output of South Africa was compared to that of its peers in the BRICS grouping using relative measure of the attractivity index and the activity index. The findings of this study indicate that some priority areas are doing well, while others are not progressing as well. It can also be deduced from the publication data that certain institutions are emerging as leaders in these research areas in the country. Wits University is a leading institution in palaeontology, UCT in energy and biotechnology while the NRF is a leader in the area of astronomy. When the progress between these areas is compared, it is clear that the investments in the area of palaeontology and astronomy are showing results, although the rate of growth in palaeontology is an area of concern. This is very interesting, as both these fields relate to South Africa's geographical advantage. Therefore, South Africa has been able to exploit its geographical advantage using a number of policy instruments and funding, particularly in the build up to the SKA bid. Publication outputs in energy and biotechnology are in line with the country's scientific output in other areas and the trend is in line with the overall growth of publication output. It is noted though that the growth in biotechnology lags far behind the overall growth of publications. Clearly the DST identified that not everything was going well in biotechnology hence the introduction of a new strategy the Bioeconomy Strategy (2013), this will hopefully help channel resources for research to the right institutions. What is positive about all of this is that despite varying levels of outputs across the different fields, the work from South Africa is highly regarded, as shown by the level of citations it attracts. Despite limited resources, the country's output in terms of publications are comparable to that of its peers in the BRICS group of countries. In a comparison of the OECD countries, it has been found that in 2012 the gross expenditure on R&D as a percentage of GDP was 0.75% for South Africa whereas the average for OECD countries is 2.39%; interestingly for China this value stood at 1.98% for 2012 (OECD, 2014). This therefore shows that South Africa is lagging behind in terms of R&D expenditure relative to other countries. This may prove to be a challenge in future in terms of maintaining the level of output as demonstrated in this study. In future, it will be interesting to consider other priority areas such as nanotechnology, information and communications technology as well as global climate change research, for a complete view of the country's performance in its chosen priority areas. Collaboration among the BRICS countries is an area that will also need to be considered in future since these countries have been developing structures to ensure closer cooperation in science.

6. References

Abramo, G., D'Angelo, C. A., & Cicero, T. (2012). What is appropriate length of the publication period over which to assess research performance? *Scientometrics*, 93, 1005-1017.

Al-bader, S., Frew, S., Essajee, I., Liu, V., Saar A., Singer P. (2009) Small but tenacious:

South Africa's health biotech sector. *Nature Biotechnology*, 27(5), 427- 444.
Balassa, B., (1965), Trade Liberalization and "Revealed' Comparative Advantage. The

Manchester School of Economic and Social Studies, 33, 99-123.

Basu, A., & Lewison, G. (2005). Going beyond journal classification for evaluation of research outputs. *Aslib Proceedings*, 57(3), 232 – 246.

Bilir, S., Onal, O., Ozturkmen, N.D., & Yontan, T. (2013). Research performance of Turkish astronomers in the period of 1980–2010. *Scientometrics,* 97, 477–489.

Bornmann, L., Wagner, C.S., & Leydesdorff, L. (2015). BRICS countries and scientific excellence: A bibliometric analysis of most frequently-cited papers. *Journal of the Association for Information Science and Technology, 66(7):1507-1513*.

Braun, T., Bujdoso, E., & Schubert A. (1987). *Literature of Analytical Chemistry: A scientometric evaluation*. Boca Raton, USA: CRC Press.

Finardi, U. (2015). Scientific collaboration between BRICS countries. *Scientometrics,* 102(2), 1139-1166.

Frame, D.J. (1977). Mainstream research in Latin America and the Caribbean. *Interciencia,* 2, 143-147.

Gauffriau,M. Larsen,P.O. Maye,I. Roulin-Perriard, A. & Von Ins, M. (2007). Publication, cooperation and productivity measures in scientific research, *Scientometrics*, 73: 175–214.

Garfield, E. (1964). Science Citation Index: A new dimension in indexing. *Science*, 144(3619), 649-654.

Glänzel, W., & Moed, H.F. (2013). Opinion paper: thoughts and facts on bibliometric indicators. *Scientometrics*, 96(1), 381-394.

Hassan, S.-U., Haddawy, P., Kuinkel, P., Degelsegger, A., & Blasy, C. (2012). A bibliometric study of research activity in ASEAN related to the EU in FP7 priority areas. *Scientometrics*, 91(3), 1035-1051.

Jacobs, D., & Ingwersen, P. (2004). South African research: 1981-2000. *Scientometrics*, 59(3), 405-423.

Kajikawa, Y., Yoshikawa, J., Takeda, Y., & Matsushima, K. (2008). *Technological Forecasting & Social Change* 75, 771–782.

Kaplan, D. (2004). South Africa's national research and development strategy: A review. *Science, Technology & Society*, 9(2), 273-294.

Kaplan, D. (2008). Science and technology policy in South Africa: Past performance and proposals for the future. *Science, Technology & Society*, 13(1), 95-122.

Kahn, M. (2011). A bibliometric analysis of South Africa's scientific outputs - some trends and implications. *South African Journal of Science*, 107(1), 1-6.

Larsen P.O. (2008). The state of the art in publication counting. Scientometrics. 77(2):235-251

Leydesdorff, L., & Gauthier, É. (1996). The evaluation of national performance in selected priority areas using scientometric methods. *Research Policy*, 25, 431-450.

Liping, D. (2011). Analysis of the relationship between international cooperation and scientific publications in energy R&D in China. *Applied Energy*, 88(12), 4229-4238.

Mansfield E. (1991). Academic research and industrial innovation. *Research Policy*, 20 (1), 1-12

Martinez, H. Jaime, A. Camacho, J. (2014). Biotechnology profile analysis in Colombia *Scientometrics.* 101, 1789 - 1804

Martinez, P. (2008). Space science and technology in South Africa: An overview. *African Skies*, 12, 46-49.

Matthews, A.P. (2012). South African universities in world rankings. *Scientometrics*, 92, 675-695.

Naravaez-Berthelemot, N., Russell, J.M., Arvanitis, R., Waast, R., & Gaillard, J. (2002). Science in Africa: An overview of mainstream scientific output. *Scientometrics*, 54 (2), 229-241.

Narin F., Hamilton K.S. & Olivastro D. (1997). The increasing linkage between U.S. technology and public science. Research Policy, 26 (3), 317-330

NEPAD Planning and Coordinating Agency (NPCA) (2014), *African Innovation Outlook 2014*, NPCA, Pretoria

OECD (2014). *OECD Main indicators database*. Paris

Pouris, A. (2012). Scientometric research in South Africa and successful policy instruments *Scientometrics*, 91, 317–325.

Pouris, A., & Pouris, A. (2009). The state of science and technology in Africa (2000–2004): A scientometric assessment. *Scientometrics*, 79(2), 297-309.

Price, D. de S. (1976). A general theory of bibliometric and other cumulative advantage processes. *Journal of the American Society for Information Science*, 27(5), 292-306.

Pritchard, A. (1969). Statistical bibliography or bibliometrics? *Journal of Documentation*, 25, 348-349.

Racki, G. (1997). Palaeontology in Science Citation Index 1995. *Lethaia*, 30, 17-18.

Racki, G., & Balinski, A. (1999). The impact factor of Acta Palaeontologica Polonica. *Acta Palaeontologica Polonica*, 44(4), 467-472.

Rousseau, R., & Yang, L. (2012). Reflections on the activity index and related indicators, *Journal of Informetrics*, 6, 413- 421.

Schubert, A., & Braun, T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. *Scientometrics*, *9*(5-6), 281-291.

Sooryamoorthy, R. (2010). Science and scientific collaboration in South Africa: Apartheid and after. *Scientometrics,* 84, 373–390.

South Africa. Department of Science and Technology. (2002). *South Africa's national research and development strategy*. Pretoria.

South Africa. Department of Science and Technology. (2001). *A national biotechnology strategy for South Africa*. Pretoria.

South Africa. Department of Science and Technology. (2007). *Innovation towards a knowledge-based economy-ten-year plan for South Africa 2008-2018*. Pretoria.

South Africa. Department of Science and Technology. (2012). *National palaeosciences strategy*. Pretoria.

Thomson Reuters. (2013). InCites™, Report created: 08 Oct 2013. Data processed Jan 31 2014, data source: Web of Science®

Van Raan, A.F.J. (1997). Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises. *Scientometrics*, 36, 396-420.

Wagner-Döbler, R. (2005). The system of research and development indicators: Entry points for information agents. *Scientometrics, 62(1),* 145-153.

Winkler, H. (2007). Energy policies for sustainable development in South Africa. *Energy for Sustainable Development*, 11(1), 26-34.

Yi, Y., Qi, W., & Wu, D. (2013). Are CIVETS the next BRICs? A comparative analysis from scientometrics perspective. *Scientometrics*, 94, 615-628.