Bibliometric analysis of bioeconomy research in South Africa

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Abstract

This document provides an analysis of bioeconomy research in South Africa and it discusses sources of growth in the country's bioeconomy literature in general. We performed bibliometric analysis as indexed in the Web of Science (WoS) for number of South African authored publications and citations in bioeconomy, and compared them with Brazil, Russia, India and China (BRICS) and selected countries for the period 2008 to 2018. The WoS is used for research dealing with the scientific dynamic of a particular topic in most widely diffused journals and for citation analysis. The results highlight South Africa ranked last in the BRICS group in terms of number of bioeconomy publications produced in the selected period, and has a world share of 0.8%, which is higher than the national research average of 0.5%. The citations growth for South Africa bioeconomy publication increased by 6.8%, higher than Brazil, Russia and world citations during the period under review. The University of Cape Town is a leader in bioeconomy publications in South Africa followed by University of Stellenbosch and the University of KwaZulu Natal, with majority of the publications on environmental sciences ecology. South Africa collaborates the most with institutions from the United States of America in bioeconomy research, and the percent of international collaboration is similar with that of national scientific publications. However, South Africa experienced a decline in bioeconomy industry collaboration publications during this period.

Introduction

Bioeconomy is a recent term following the term biotechnology. "Bioeconomy is the production, utilisation and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide information, products, processes and services across all economic sectors aiming toward a sustainable economy" (GBS 2018). The Organisation for Economic Co-operation and Development (OECD) defines bioeconomy as "a world where biotechnology contributes to a significant share of economic output" (OECD 2009). The German government's Bioeconomy Council (2018) defines bioeconomy as "the knowledge based production and use of biological resources to provide products, processes and services in all economic sectors within the frame of a sustainable economic system". The European Union defines bioeconomy as "the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based

products as well as bio-energy" (EC 2012). South Africa's bioeconomy strategy defines the term bioeconomy as "activities that make use of bio-innovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development" (DST 2013). Definition of bioeconomy vary depending on the country specific economic, ecological and social demands (Lier et al 2018; 2019). However, it is evident that the South Africa's definition of bioeconomy is broadly in accordance with definitions employed in other bioeconomy strategies globally.

According to the OECD (2009), bioeconomy is likely to involve "advanced knowledge of genes and complex cell processes, renewable biomass, and the integration of biotechnology applications across sectors". Biotechnology is a broad term that covers the practical use of biological systems to provide goods and services (Bull, Holt and Lilly 1982; Sridhar 2005; Chekol and Gebreyohannes 2018). Biotechnology is considered a key sector for future economic growth and it has been the main driver for the development of environmentally sustainable production practices and the development of various innovative products. Biotechnology thus has the potential to contribute to social development by for example, ensuring community involvement and the protection of indigenous knowledge.

In context to this study, biotechnology is a broad definition which focus on the development of new processes and products while bioeconomy subsumed under the biotechnology definition however with more focus on innovative economic activities.

Bioeconomy is now rapidly expanding in the 21st century. There are eight countries with a dedicated bioeconomy strategy, namely; Finland, Germany, Greenland, Iceland, Japan, Malaysia, South Africa and United States of America. Other countries – more than 50 countries – have some policy elements on bioeconomy, however they do not have a dedicated strategy. Until now, more and more countries are developing strategies and polices related to biotechnology and bio-based products and industries (Staffas, Gustavsson and McCormick 2013). South Africa adopted a coordinated approach to develop a bioeconomy strategy, and as articulated in its National Development Plan (NDP 2012), which require that research and innovation by universities, science councils, departments and non-government organisations (NGOs) and the private sector contribute in improving the country's global competitiveness. Coordination between these different roles players is suggested as one of the fundamental issues needing attention.

The bioeconomy strategy in South Africa, coordinated by the Department of Science and Innovation (DSI), identified three key economic sectors that are likely to benefit, namely agriculture, industrial and environmental bio-innovation and health, with indigenous knowledge systems (IKS) as an important crosscutter contributing to the activities within these three sectors (DST 2013).

The objectives of the South Africa's bioeconomy strategy are to make South Africa more competitive internationally; to create more sustainable jobs; to enhance food security; and to create a greener economy as the country shifts towards a low-carbon economy (DST 2013). The strategy outlines a systems approach to be taken for the development of bioeconomy, recognising the complex and non-linear nature of innovation, and the diversity of 'actors', role-players, institutions, policies and regulations. The roles of the various stakeholders are ideally complementary, supportive, and additive, and it is the collective whole that contributes to bioeconomy. Under the strategy there are a variety of priority issues, including value chain competence, partnerships and coordination. In the United States of America, government enhance and coordinate communication between different domestic agencies and entities, and establish protocols for sharing data (USDA 2011). According to FAO (2016), these efforts should go hand-

in-hand with the development of relevant and comprehensive guidelines on how to measure the sustainability of bioeconomy at international level. The bioeconomy strategy of South Africa further identified several indicators as elements of a bioeconomy measurement framework. The National Advisory Council on Innovation (NACI) in South Africa, which advices the Minister of Science and Innovation in South Africa on the role and contribution of science, mathematics, innovation and technology, among others, indicated that the strategy did not clearly outline the measurement framework to monitor the implementation of the strategy over time. The NACI established a project team to provide a complete indicators framework suitable for the measurement, evaluation and monitoring of the implementation of the strategy. The DSI which coordinates the bioeconomy strategy of South Africa contributes to bioeconomy through the encouragement and enhancement of innovation and technological advancement. The NACI recommends that the DSI measure innovation and technological change in bioeconomy through resources committed to enhance innovation and technological change in bioeconomy; and through output measures such as the number of bioeconomy publications and citations in peer reviewed journals, the number and share of South African patents and citations in bioeconomy, and output attributed to innovation by firms in bioeconomy. This paper seeks to investigate output measures based on publications and citations as recommended by NACI.

The aim of this document is to describe the growth of bioeconomy research in South Africa by analysing publication and citation trends in the area of bioeconomy. Bioeconomy is recent and still in its fancy, and this present novelty of the study. The literature on this subject is mainly focused on the term biotechnology. The study is important in informing baseline information for the development of appropriate metrics for the measurement of progress of the bioeconomy in South Africa. The objectives of the study are to 1) measure the number of South African authored publications covering bioeconomy disciplines using the Web of Science (WoS) database; 2) measure the citations of South African authored publications covering bioeconomy disciplines as indexed to the WoS using InCites^{TM} database; and 3) compare the results with Brazil, Russia, India and China (BRICS), and to a certain extent, with Egypt, Germany, Malaysia and the United States of America (USA). The study is important for the development of scientific outputs for the measurement of progress of innovation change in bioeconomy in South Africa. A comparison of the changes of scientific outputs as compared to changes in outputs over time with the selected countries will allow an assessment of the efficiency of bioeconomy innovation system in South Africa. Accordingly, in addition for performance measures that assess scientific outputs for bioeconomy, technological change and economic outputs must be developed for the complete assessment of the efficiency of bioeconomy innovation system. This document investigates only the scientific publications. Scientific publications disclose some of the peer-reviewed outcomes of research efforts (OECD 2016). The BRICS countries are selected for this purpose as they are considered five major emerging national economies, and the countries have been working towards closer cooperation between the members in scientific disciplines. Therefore a benchmark amongst these countries present a fair comparison. The BRICS have previously been studied by a number of authors to compare the scientific (Bornmann, Wagner, and Leydesdorff 2015; Makhoba and Pouris, 2016; 2017) and technology (Makhoba and Pouris; 2019b) outputs within the group. Germany, Malaysia and USA have dedicated bioeconomy strategies (The White House 2012; AIM 2013; BMBF and BMEL 2015; MOSTI and Bioeconomy Corporation 2016) and represents multiple continents, while Egypt is the second most productive country in Africa in terms of research publications (Naravaez-Berthelemot et al 2002).

Bibliometric analysis of bioeconomy and biotechnology

Bibliometric studies provide systematic analysis of the research system across time and countries (Pereira 2000). Bibliometric studies of biotechnology mainly focus on understanding development status and trends in terms of research publications and patents. Bibiliometric studies of biotechnology dates back as early as the 1980s (Rip and Courtial 1984; Kochhar and Verma 1987; Nordstrom 1987; Nederhof 1988; Singh and Saxena 1992; Thomas 1992; DeLooze 1994; Lewison 1994; Martens and Saretzki 1994; Zucker, Darby and Brewer 1994; McCain 1995a; McCain 1995b; Hinze and Grupp 1996; DeLooze and Lemarié 1997; DeLooze and Ramani 1999; Banerjee, Gupta and Garg 2000; McMillan, Narin and Deeds 2000; DeLooze, Coronini and Joly 2001; Leydesdorff and Heimeriks 2001). The literature on bibliometric studies of biotechnology was mainly based on the use of Science Citation Index (SCI) (Thomas 1992; Zucker et al 1994; McCain, 1995b; Leydesdorff and Heimeriks 1998; DeLooze et al 2001) or Derwent Biotechnology Abstracts (DBA) (Kochhar and Verma 1987; Singh and Saxena 1992; McCain 1995a; McCain 1995b; Hinze and Grupp 1996; Leydesdorff and Heimeriks 1998; DeLooze and Ramani 1999; Banerjee et al 2000; McMillan et al 2000; DeLooze et al 2001) databases. The SCI database was mainly used for analysis of publications while DBA database was mainly used for analysis of patents. For example, DeLooze et al (2001) used the SCI and DBA databases to analyse scientific publications and applications for patents in the field of genomics. Banerjee et al (2000) used the DBA to compare the change in patenting activity in biotechnology for selected periods. Leydesdorff and Heimeriks (2001) used the SCI and title words of scientific publications in five core journals of biotechnology to distinguish between the intellectual organisation of the publications in Europe, United States of America and Japan. However, other researchers have used the DBA to study the literature trends in biotechnology. Singh and Saxena (1992) used the DBA database to analyse references collected in mass health care from biotechnology applications for the period of 1983 to 1987 to study the literature trend in this area. The literature review on the use of SCI and DBA databases in bibliometrics studies in biotechnology are detailed by Dalpé (2002). The two databases are now maintained by Clarivate Analytics – through the Web of Science (WoS). There are several papers already documented on the use of the WoS in bibibliometric studies on biotechnology. Sevukan and Sharma (2008) provided an analysis of research performance of biotechnology faculties in central universities of India from 1997-2006. More recently, (Makhoba and Pouris 2016) investigated biotechnology publications in South Africa compared with the fields of energy, astronomy and palaeontology, using the WoS database for the period 2002–2012.

There are other databases such as Scopus and Google Scholar that were recently considered by other researchers in bibliometrics studies in biotechnology, however were not part of this study. Bajwa and Yaldram (2013) studied research trends in Pakistan in the field of biotechnology using Scopus database for the period 1980-2011. López-Illescas et al (2009) compared bibliometric country-by-country rankings derived from the WoS and Scopus in the field of oncology. Scopus is interdisciplinary and covers a wider journal range compared to the WoS that is subject specific (Wagner 2015), however Scopus is currently limited to recent articles compared to the WoS (Falagas et al 2008). In terms of citation, Google Scholar data is not comparable to data from other bibliometric databases such as the WoS and Scopus (Aguillo 2012). A study by Martín and Martín et al (2018) found that most citations found only by google scholar compared to WoS and Scopus were from non-journal sources as well as non-English language journals. Scopus and Google

Scholar are time consuming in terms of data collection and processing compared to the WoS. In analysing of more than 10000 citing and purportedly citing documents, the WoS data took about 100 hours of collecting and processing time. Scopus and Google Scholar took about 200 and 3000 hours respectively (Meho and Yang 2006).

Bibiliometric studies using keyword bioeconomy are still in their infancy as bioeconomy is a recent term following the term biotechnology. A paper by Bugge, Hansen and Klitkou (2016) based their bibliometric analysis of bioeconomy on a literature retrieval of relevant scientific articles indexed from the Core Collection of WoS. They concluded that the delimitation of a sample can be defined by the chosen publishing period, the geographical location of the authors, the selection of research areas, the selection of a journal sample, or the selection of keywords. In a paper by Rodríguez-Salvador et al (2017), the researchers used the WoS and Scopus databases to retrieve scientific publications in the field of 3D bioprinting. The 3D bioprinting are used in research drugs and pills, which form part of the bioeconomy. Yao et al (2014) used the WoS to evaluate global scientific production and develop trends of health systems research from 1900 to 2012 to provide data on the current status and impact of the health systems research globally. Pfau et al (2014) used a multi-disciplinary approach for bibliometric analysis of bioeconomy. The authors chose multiple databases in order to cover a broad range of literature that might address bioeconomy. Five databases from the fields of natural and environmental sciences, economics and social sciences were selected including the WoS to investigate the relationship between bioeconomy and sustainability by means of a systematic review.

The research in this paper is important to understand the development status and trends in the field of bioeconomy. The data for bibliometric analysis was retrieved using keywords bioeconomy and biotechnology from the WoS and citations analysed using InCites tool for period 2008 to 2018.. The WoS and InCites tools are maintained by the Clarivate Analytics database and are discussed in details in the section below. Relevant journals with the largest number of records are all covered by the Clarivate Analytics database. The WoS and InCites therefore offer appropriate and timely sources to depict publication activities and citations impacts on specific subject fields.

Methodology

In this paper we use bibliometric analysis to observe the growth of bioeconomy research in South Africa, and in order to position the country's overall bioeconomy through the overall production of literature in an international context such as the Brazil, Russia, China and India (BRICS nations), and selected countries such as Egypt, Germany, Malaysia and United States of America.

Bibliometric analysis is considered one of the most effective methods in assessing research performance, and for comparisons of different disciplines, collaboration profiles, comparisons of countries, changes over time and others which are not possible through other methods such as peer review. Bibliometrics analysis was performed on the data obtained from the WoS Core Collection database for publications and citations. The data for citations was exported to InCites database for analysis. The WoS is an online subscription-based scientific citation indexing service originally produced by the Institute for Scientific Information (ISI), later maintained by Clarivate Analytics. The WoS provides a list of cited articles, each of which is accompanied by a list of citing articles (Garfield 1964). The WoS is used for research dealing with a particular topic in most widely diffused journals and for citation analyses. InCites is an analytical tool provided by Clarivate

Analytics which uses the same underlying data from the WoS and is used to gather the total number of citations for each country by year

The WoS Core Collection database was used for the search of publications from South Africa and compared with that from the BRICS, Egypt, Germany, Malaysia and USA. A number of studies in bioeconomy and biotechnology research have conducted bibliometric analysis using the WoS (Sevukan and Sharma 2008; Pfau et al 2014; Bugge et al 2016; Makhoba and Pouris 2016).

The analysis was limited to articles only as the focus of the study is on scientific research outputs, and this approach is documented in other papers (Makhoba and Pouris 2016). Data was limited to ten years, i.e. 2008 to 2018, as most of bioeconomy strategies were developed during this period. Germany is among the first countries to develop bioeconomy strategy in 2010 (BMBF and BMEL 2015). This period is also important in South Africa as it falls under the ten-year innovation plan - towards a knowledge-based economy (DST 2007). Further, bioeconomy to 2030: designing policy agenda was published in 2009 by the Organisation for Economic Co-operation and Development (OECD 2009), signaling the beginning of bioeconomy "era". The book provided guidance to countries' development of bioeconomy strategies and explores policy options to support the social, environmental and economic benefits of a bioeconomy. Therefore, it would not have added value in bioeconomy context to go back further than 2008. The data search was conducted up to 2018. For citations, data analysis included all types of citation indexes (i.e. science, social science, humanities etc) as bioeconomy cross-cuts many fields of sciences. This approach is documented by Pfau et al (2014) as the authors used a multi-disciplinary approach for bibliometric analysis of bioeconomy.

To create a complete picture on the number of South African authored publications and citations in bioeconomy in peer reviewed international journals, both keywords bioeconomy and biotechnology were considered for the analysis as publication data is generally organised by scientific field, and not by economic sector. Further, within the bioeconomy definition, biotechnology is a common thread, and therefore its inclusion will cover most of the field in the bioeconomy. The following keywords and their variants were selected as suggested in the literature (Sevukan and Sharma 2008; Bajwa and Yaldram 2013; Pfau et al. 2014; Bugge et al. 2016): bio* OR "bioeconomy" OR "bio-economy" OR "bio economy" OR biobased* OR "bio based*" OR "bio-based*" OR "biobased economy*" OR "bio based economy*" OR "bio-based economy*" OR "biomass based economy*" OR "biomass-based economy*" OR "biotechnology". In this case, a top down keyword search and Boolean operators were used. The search results were carried out with at least one South African resident as an author or co-author. The same strategy was used to collect data for selected countries, only by changing the name of the country of resident.

We then used InCites to gather the total number of citations for each country by year up to 2015. The years 2016, 2017 and 2018 were not considered for the total citations analysis to allow the three years to gather full citations. These citations were then totaled to create a measure of the quality of the scientific production for each country for the selected period.

A descriptive approach was used to identify the trends based on the publication data. The analysis focused on investigating countries with which South Africa collaborates the most on bioeconomy research, the most prolific research institutions in bioeconomy research in the country, the top journals selected by South African researchers, the subject categories, as bioeconomy is a multidisciplinary field, percentage of publications in top 1% and top 10%, and percentage of international and industry collaborations.

Results and discussion

Analysis of the WoS database identified 19040 publications in bioeconomy disciplines with at least one South African author for the period 2008-2018 (Table 1). The number of South African bioeconomy publications has shown a rising trend for this period, however the growth rate is varying, with an average of 11.3% (Fig. 1). The number of publications were low in 2012 and highest in 2015. It is noteworthy that South Africa launched the Biotechnology Strategy in 2001 (DST 2001) and the Bioeconomy Strategy in 2014 (DST 2013). The launch of the Biotechnology Strategy was accompanied by government financial support however, the 2014 launch of the Bioeconomy Strategy did not attract much additional funding from government. The number of South African publications in general has shown a rising trend for the same period (Fig. 2). The finding is similar to that of Kahn (2011) who found that the number of South African journals indexed to the WoS increased in recent years, which may have contributed to increase in South African authored publications. The New Funding Framework (NFF) for higher education institutions in South Africa introduced in 2003 also positively affected the number of publications in South Africa (Pouris 2012). The increase in scientific publications in South Africa is further attributed to the increase in international research collaborations (NACI 2017). The citations trend for bioeconomy research with at least one South African author for the same period shows an inconsistent growth rate, with the period 2009 to 2010 and 2012 to 2013 displaying the highest growth rates. The total citations for South African research publications in general has shown a rising trend between 2008 to 2012 but has been on a decline post 2013 (Fig. 2). The citations trend for bioeconomy research with at least one South African seems higher than the total citations for South African research publications during the same period.

Table 1 South Africa bioeconomy research publications and citations by year, 2008-2018

Year	Total number of publications	Growth rate (%)	Total citations	Growth rate (%)
2008	893		27163	
2009	1002	12.2	26370	-2.92
2010	1171	16.9	34275	29.9
2011	1359	16.1	36831	7.46
2012	1405	3.38	26919	-26.9
2013	1666	18.6	33271	23.6
2014	1809	8.58	30068	-9.63
2015	2133	17.9	28997	-3.56
2016	2462	15.4	21948	-24.3
2017	2568	4.31	13344	-39.2
2018	2572	0.16	5667	

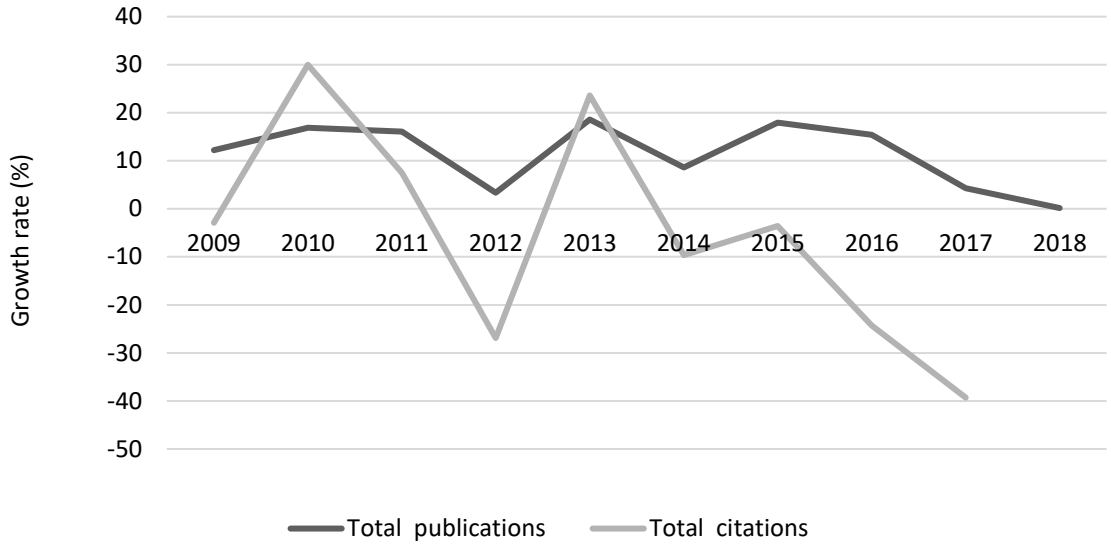

Fig. 1 The publication and citation growth for bioeconomy in South Africa from 2009 to 2018.

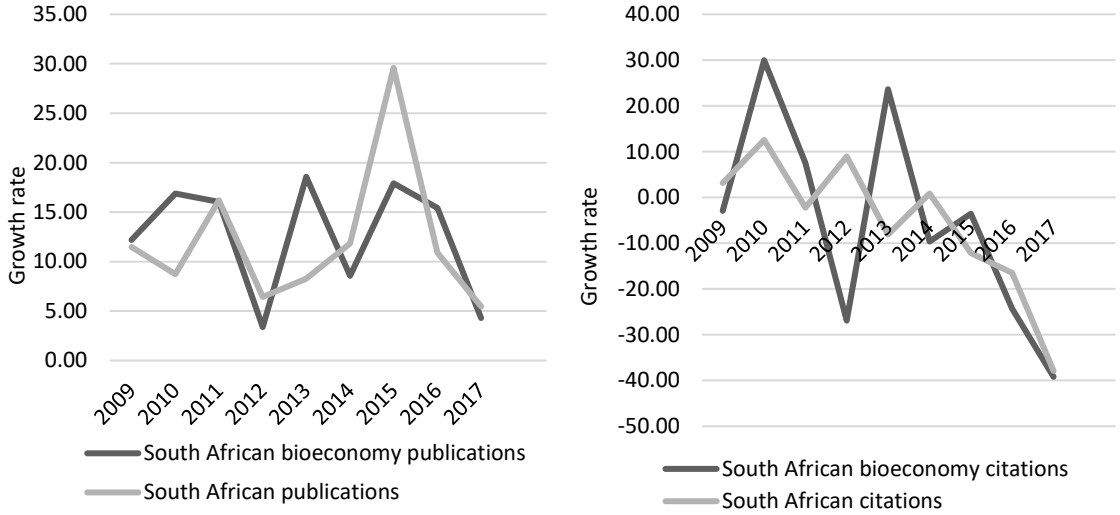

Fig. 2 South African bioeconomy research publications and citations growth rates in comparison to South African total research publications and citations, 2009 to 2017

Table 2 South Africa total bioeconomy publications, 2008-2018

Year	Percentage documents cited	Percentage international collaborations	Percentage industry collaborations	Percentage documents in top 1%	Percentage documents in top 10%
2008	97.20	48.15	1.46	1.57	12.65
2009	97.01	51.10	1.60	1.20	9.580
2010	94.71	48.42	1.28	1.62	12.21
2011	96.17	52.06	1.18	2.58	12.67
2012	95.73	51.53	1.14	1.35	11.03
2013	94.48	55.13	1.56	2.16	13.92

2014	94.19	55.67	1.16	1.55	12.84
2015	91.97	56.84	1.30	2.74	13.52
2016	87.99	57.87	1.38	1.73	11.88
2017	81.91	60.08	0.87	1.58	11.66
2018	57.93	63.63	1.18	2.15	11.48

Pouris (2006) conducted citation analysis of South African scientific disciplines from six universities and concluded that the country has citation foot-prints in only nine of the 22 broad scientific disciplines. All the nine scientific disciplines are covered in the bioeconomy sector. This could explain the higher citation growth rates for bioeconomy in South Africa in comparison to the total citations for South African research publications during the same period. In South Africa the health-related scientific publications is responsible for the largest single contribution from South Africans authors as indexed in Thomson Reuters ISI system (ASSAf 2009), now the WoS. On average (Table 2), 90% of South Africa bioeconomy publications were cited up to 2018, however the appropriate duration for citation time is at least three years in order to provide reliable citation data (Abramo, D' Angelo and Cicero 2012). The average citation for up to the year 2015 is at 95%. About 55% of bioeconomy publications with at least one author from South Africa were written in collaboration with researchers from other countries. The observation is slightly equivalent to the national percentage on international collaborations between 2007 and 2016, which is at 53% (NACI 2017). Kahn (2011) found that the collaboration profile of South African scientific publications with foreign co-authors increased during 1990 to 1994 and 2004 to 2008 periods respectively, and suggested that "it is this factor that best accounts for the rise in number of scientific publications by South Africans". The average percentage industry collaboration, publications in top 1% and publications in top 10% for South African bioeconomy publications is at 1.3%, 1.8% and 12.1% respectively, which is on par with the national average of 1.4% for both industry collaboration and publications in top 1% respectively, but slightly higher than the national average publications in top 10% which is at 9.8% for period 2007 to 2016. In South Africa, the percentage of international collaborations for bioeconomy publications increased from 48.15% in 2008 to 57.87% in 2016, slightly higher than the national total scientific publications percentage of international collaborations which increased from 40.46% in 2008 to 52,82% in 2018 (NACI 2017).

Table 3 Number of South Africa bioeconomy publications in comparison with selected countries in alphabetical order, 2008-2018

Countries	Bioeconomy publications	World share (%)	World ranking
Brazil	90863	3.95	11
China	371952	16.2	02
Egypt	20928	0.91	28
Germany	164982	7.17	03
India	117394	5.10	05
Malaysia	19042	0.83	34
Russia	32648	1.42	22
South Africa	19040	0.83	33

USA	609403	26.5	1
World	2300174	100	

Among the BRICS countries (Table 3), China had the most publications, followed by India, Brazil, Russia and then South Africa. This observation is similar to the OECD (2016) compendium of bibliometric science indicators which reported a five-fold increase in publications from China, for period 2003 to 2012. South Africa, Malaysia and Egypt had almost equivalent number of publications, that is 19040, 19042 and 20928 respectively. South Africa and Malaysia did not differ in terms of world share (0.83%). South Africa rank 33 in the world in terms of the number of bioeconomy publications.

Table 4 Bioeconomy publications by year for world total and Brazil, Russia, India and China (BRICS)

Year	World	Growth rate (%)	Brazil	Growth rate (%)	Russia	Growth rate (%)	India	Growth rate (%)	China	Growth rate (%)
2008	131707		4407		1631		5082		11442	
2009	146697	11.4	5069	15.0	1805	10.7	5598	10.2	14442	26.2
2010	161985	10.4	5716	12.8	1960	8.59	6712	19.9	17061	18.1
2011	177665	9.68	6476	13.3	2009	2.50	7641	13.8	20804	21.9
2012	189372	6.59	7106	9.73	2025	0.80	8559	12.0	25297	21.6
2013	203492	7.46	7784	9.54	2171	7.21	9640	12.6	31289	23.7
2014	217103	6.69	8416	8.12	2548	17.4	10769	11.7	37398	19.5
2015	246165	13.4	9965	18.4	3656	43.5	14286	32.7	43582	16.5
2016	262449	6.62	10917	9.55	4298	17.6	15578	9.04	49867	14.4
2017	275633	5.02	12208	11.8	4974	15.7	16508	5.97	56244	12.8
2018	287906	4.45	12799	4.84	5571	12.0	17021	3.11	64526	14.7

As can be seen on Table 4, the number of bioeconomy publications for selected countries for period 2008 to 2018 have shown a rising trend for this period, however as was seen with South Africa, the growth rates are varied.

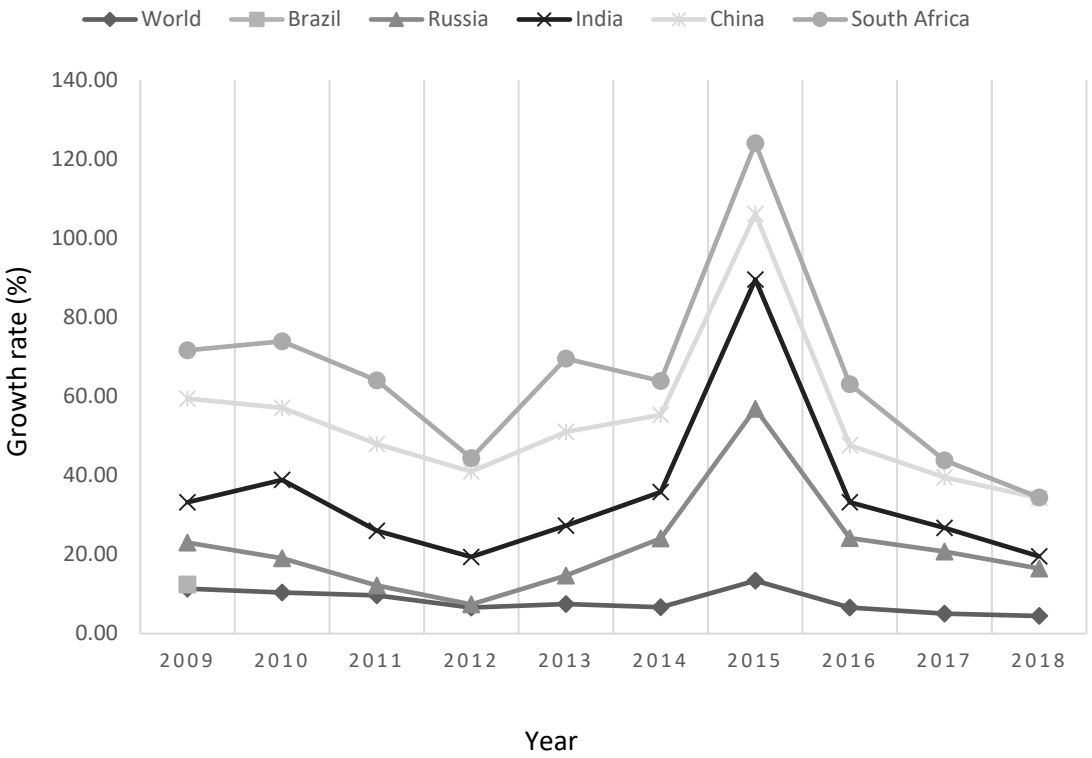

Fig. 3 Bioeconomy publications trends in South Africa in comparison to world total and Brazil, Russia, India and China (BRICS), 2009-2018

As can be seen on Fig. 3, the BRICS countries experienced the lowest publications growth rate in 2012. The publications growth rate for the BRICS begin to increase in 2013 and reached the highest growth rate in 2015. This increase is reflected in word total publications in terms of growth rate. In 2014, the WoS begin to host the SciELO Citation Index covering Brazil, Spain, Portugal, the Caribbean and South African, and 12 more countries of Latin America. Further, in 2015, the Russian Science Citation Index was introduced to the WoS database to increase the citation of Russian publications by the world scientific community. The WoS was further expanded in 2015 to include the journals of the Emerging Sources Citation Index (ESCI) that includes peer-reviewed publications of regional importance and in emerging scientific field. These could explain the sudden increase and high growth rate of publications in 2015. Growth rates seem to be on a decline post 2015. South Africa had a growth rate of 12.2% in 2009 in terms of bioeconomy total publications and increased to 15.45% in 2016, however the growth rate has declined to 4.31% and 0.16% in 2017 and 2018 respectively.

Table 5 Bioeconomy citations by year for world and Brazil, Russia, India, China and South Africa (BRICS), 2008-2015

Year	World	Growth rate (%)	Brazil	Growth rate (%)	Russia	Growth rate (%)	India	Growth rate (%)	China	Growth rate (%)	South Africa	Growth rate (%)
2008	4346195	1.00	101882		31415		122359		379953		27163	
2009	4389507	3.17	109458	7.44	30411	-3.20	137142	12.08	456329	20.10	26370	-2.92

2010	4528846	-3.42	109329	-0.12	32212	5.92	147864	7.82	535056	17.25	34275	29.98
2011	4373976	-5.83	111131	1.65	31837	-1.16	150502	1.78	586101	9.54	36831	7.46
2012	4118845	-6.35	108134	-2.70	39770	24.92	149003	-1.00	688981	17.55	26919	-26.91
2013	3857240	-10.49	109100	0.89	31809	-20.02	149611	0.41	676367	-1.83	33271	23.60
2014	3452774	-5.74	104375	-4.33	34720	9.15	145805	-2.54	689447	1.93	30068	-9.63
2015	3254618		95474	-8.53	27586	-20.55	136478	-6.40	642024	-6.88	28997	-3.56

The total citations for the BRICS are shown in Table 5. South Africa recorded 27163 total citations in 2008 and 28997 in 2015, a 6.8% increase. The total citations for all BRICS members are gradually increasing in general although the growth rates are inconsistent. China experienced the highest growth increase, that is 69% growth rate during this period. Brazil recorded a decrease -6.29% in this period.

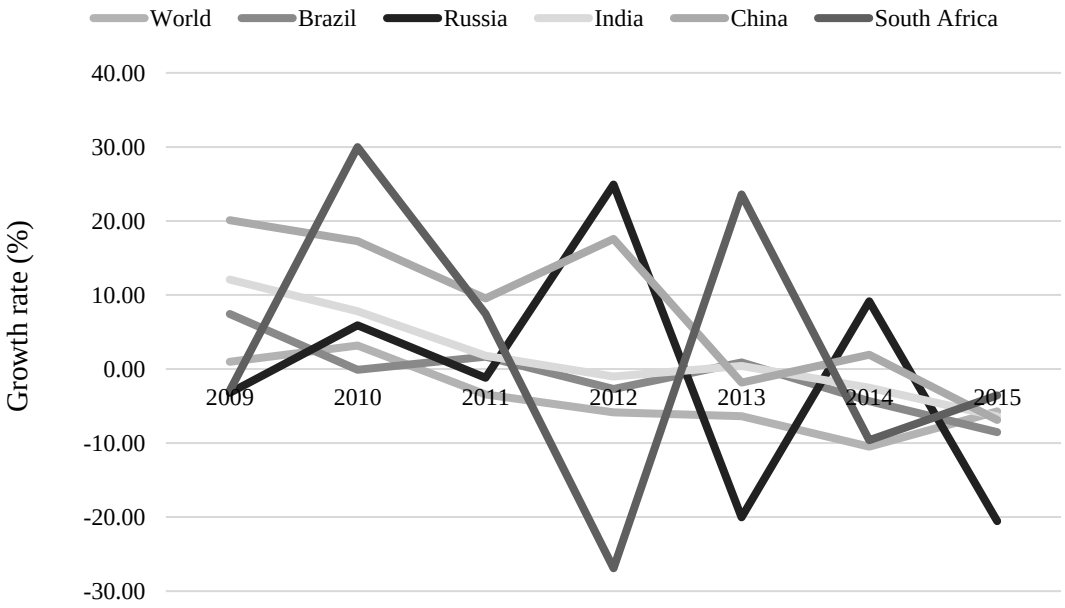

Fig. 4 Bioeconomy citations trends in South Africa in comparison to Brazil, Russia, India, China and world, 2009-2015

South Africa (Fig. 4) recorded the highest total citations in the year 2010 and the lowest total citations in 2012 among the BRICS.

Table 6 The top 20 journals publishing most articles on bioeconomy in South Africa, 2008-2018

Journal	Impact Factor*	No. of publications	Percentage of total	Country
PLoS One	2.776	468	2.46	United States of America
South African Journal of Botany	1.504	335	1.76	South Africa
African Journal of Marine Science	0.991	155	0.81	South Africa

Water SA	0.896	150	0.79	South Africa
African Entomology	0.536	139	0.73	South Africa
South African Journal of Science	1.351	121	0.64	South Africa
African Journal of Aquatic Science	0.75	118	0.62	South Africa
Scientific Reports	4.011	116	0.61	England
Biological Conservation	4.451	112	0.59	England
Biological Invasions	2.897	108	0.57	Netherlands
African Journal of Biotechnology	0.573	90	0.47	Kenya
Zootaxa	0.99	89	0.47	New Zealand
African Zoology	0.962	86	0.45	South Africa
SAMJ South African Medical Journal	1.316	85	0.45	South Africa
Molecular Phylogenetics and Evolution	3.992	83	0.44	United States of America
Journal of Ethnopharmacology	3.414	82	0.43	Ireland
Marine Ecology Progress Series	2.359	68	0.36	Germany
Molecules	3.06	68	0.36	Switzerland
Bioresource Technology	6.669	67	0.35	Netherlands
Diversity and Distributions	4.092	67	0.35	England

*Journal impact factor as published in the Journal Citation Reports of Clarivate Analytics for the year 2018.

In South Africa, most of the articles on bioeconomy appeared in the Journal PLoS One (468) followed by South African Journal of Botany (335), Table 6. The African Journal of Marine Science, Journal Water SA and Journal African Entomology followed with 155, 150 and 139 number of publications respectively for the period 2008 to 2018. PLoS One Journal covers primary research from disciplines within science and medicine (Dash Nelson and Rae 2016; Boë et al 2017; Fuss et al 2017; Gravett et al 2017; Hallmann et al 2017; Lance et al 2017; Mack and Wrase 2017). Scientific disciplinary performance of South Africa between 1996 and 2016 was the highest in the life sciences in terms of the number of publications, with a percentage share of 45.5 (NACI 2017). This could explain the highest number of bioeconomy articles in the Journal PLoS One for South Africa.

Table 7 Bioeconomy classification according to research domains in South Africa and their occurrence, for selected top 20, 2008-2018

Research area	Record count	Percentage of total
Environmental Sciences Ecology	3391	17.8
Chemistry	1419	7.45
Plant Sciences	1418	7.45
Science Technology Other Topics	1339	7.03
Biochemistry Molecular Biology	1125	5.91
Biotechnology Applied Microbiology	1071	5.63
Marine Freshwater Biology	937	4.92
Agriculture	920	4.83
Biodiversity Conservation	903	4.74

Engineering	884	4.64
Pharmacology Pharmacy	875	4.60
Zoology	766	4.02
Entomology	638	3.35
Geology	628	3.30
Microbiology	578	3.04
Water Resources	498	2.62
Evolutionary Biology	487	2.56
Materials Science	475	2.49
Infectious Diseases	437	2.30
Life Sciences Biomedicine Other Topics	403	2.12

Table 7 shows that environment, chemistry and plant sciences research attract substantially more attention than the biotechnology related disciplines. These findings confirm previous findings (Pouris 2003; Pouris and Pouris 2009a) that "active South African disciplines are those involving natural wealth, that is ecology, environment, geosciences, plant and animal sciences and space science". This observation is similar in European Union where bioeconomy strategies focus on sustainability and environmental management such as reducing waste-streams of bio-resources and developing new products and economic value chains based on existing waste-streams (Bugge et al 2016).

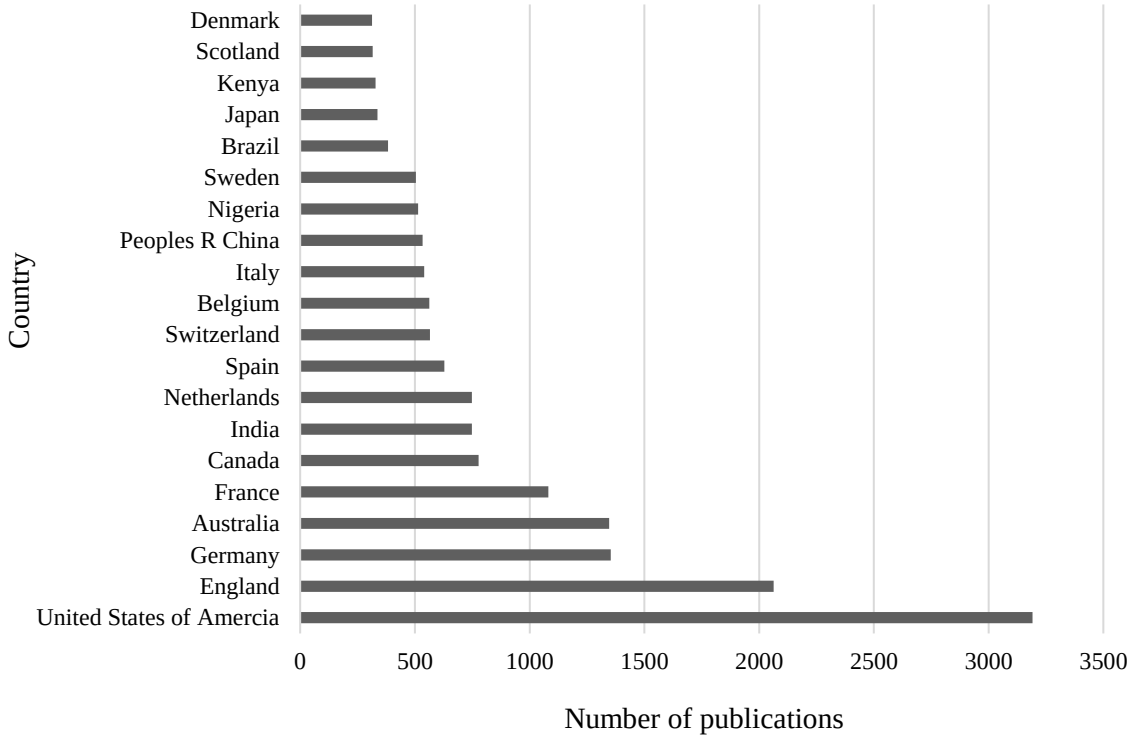

Fig. 5 Bioeconomy collaboration profile of South Africa with other countries, 2008-2018

As can be seen on Fig. 5, South Africa collaborates the most with the United States of America, followed by England and Germany. These findings confirm previous findings (Pouris and Pouris 2009a). Collaboration in bioeconomy in South Africa is substantially on par with the national average in terms of the top five collaborative countries (Fig. 6). It is noteworthy that previously, the collaboration in biotechnology related disciplines was higher than the national average (Pouris and Pouris 2009a).

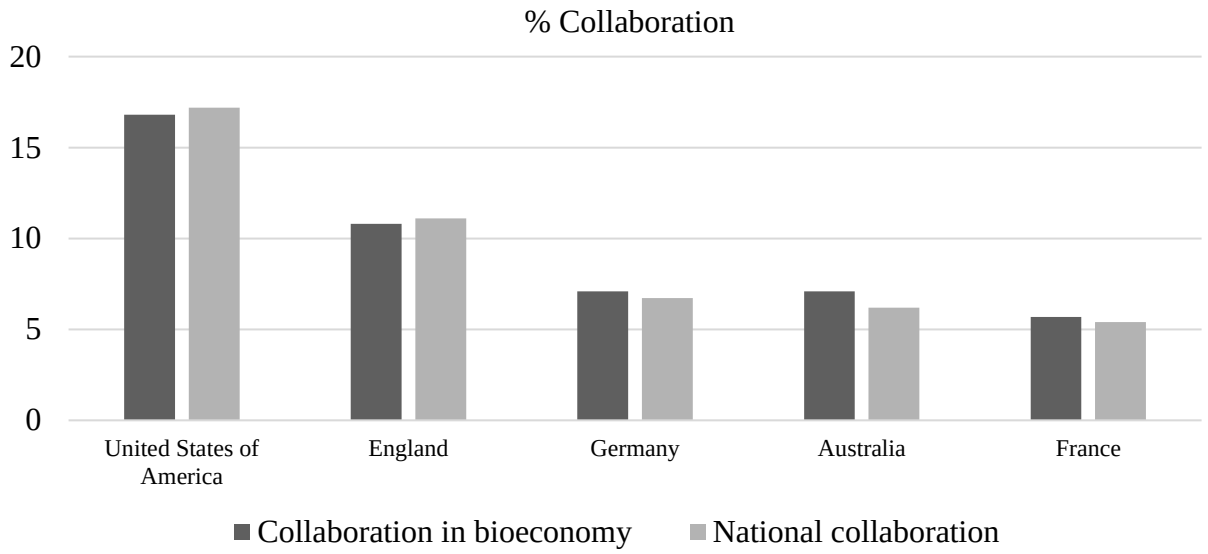

Fig. 6 Bioeconomy collaboration network in South Africa

The publication outputs of various institutions are shown in Table 8. As expected, the University of the Cape Town, University of Stellenbosch, University of KwaZulu Natal, University of Pretoria and University of the Witwatersrand are leading with 13 408 South African bioeconomy publications. This conforms to the findings by Matthews (2012) and Makhoba and Pouris (2016). The findings represents 70.4% of all bioeconomy publications with at least one South African author for the period 2008-2018. This observation is similar with NACI observation on South Africa general publications where these top five universities account for 78.2% of the publications from universities (NACI 2017).

Table 8 Top 20 producers of bioeconomy publications in South Africa, 2008-2018

Affiliation	Articles	% articles published
University of Cape Town	3238	17.01
University of Stellenbosch	3149	16.54
University of KwaZulu Natal	2697	14.16
University of Pretoria	2415	12.68
University of Witwatersrand	1909	10.03
Rhodes University	1065	5.59
University of Johannesburg	1058	5.56

North West University	977	5.13
Council for Scientific and Industrial Research	776	4.08
University of the Free State	664	3.49
University of the Western Cape	592	3.11
Nelson Mandela Metropolitan University	628	3.30
University of the Free State	462	2.43
Tshwane University of Technology	425	2.23
University of Fort Hare	350	1.84
Tshwane University of Technology	425	2.23
University of Fort Hare	350	1.84
Durban University of Technology	270	1.42
Cape Peninsula University of Technology	257	1.35
University of Limpopo	248	1.30

Bioeconomy and related research in South Africa

The document provides bibliometric analysis of bioeconomy research in South Africa and it discusses sources of growth in the country's bioeconomy publications. Since 2008, the research publications on bioeconomy in South Africa is increasing noticeably and is comparable with that of the BRIC countries. Although South Africa rank last and 33rd in the world in terms of bioeconomy publication, the field appears to have taken off with 893 publications recorded in 2008 compared to 2572 in 2018. In terms of total citations for period 2008 to 2015, over 95% of publications are cited. The South African bioeconomy research total citations trends recorded the highest citations in 2010 among the BRICS but was lowest in 2012. These discrepancies were observed among the BRICS group in general. The universities of Cape Town and Stellenbosch appear to be the main producers of bioeconomy publications in South Africa, followed by the universities of KwaZulu Natal, Pretoria and Witwatersrand with small differences in their publication profiles. The subject area Environmental Sciences Ecology was the most popular and the Journal PLoS One appear to be the main vehicle for reporting research results in the field of bioeconomy from South Africa. The collaboration profile for South Africa in the bioeconomy field appears to follow the trend as with South African scientific publications in terms of international collaboration, increasing from 48% in 2008 to 64% in 2018. This resulted in an increase in the quality of scientific output as the percentage of publications in the top 1% increased from 1.57% in 2008 to 2.15% in 2018. Bioeconomy publications collaborations within industry seems to be on a decrease, from 1.46% in 2008 to 1.18% in 2018, which is a concern. Nationally, industry scientific collaborations are on the increase, from 1.06% in 2007 to 1.35% in 2007 (NACI 2017).

Conclusion

Biotechnology in South Africa has come a long way since the biotechnology strategy (DST 2001) was released in 2001. A paper (Pouris and Pouris 2009b) found the South African "average growth in biotechnology related publications to be 64% between 1995 to 2006". During 2008 to 2018, the ten-year innovation (2007) and the bioeconomy strategy (2013) periods, there was an average growth in South African bioeconomy related publications from 893 in 2008 to 2572 in 2018, a

188% growth rate as compared to 119% growth rate of bioeconomy world publications. In comparison to Brazil, Russia, India and China, South Africa needs to increase its research publications by a factor of 1.7, 4.8, 6.1 and 20 to produce equivalent volume of knowledge production similar to Russia, Brazil, India and China respectively. The citation growth during 2008 to 2015 period for South African bioeconomy related publications increased from 27163 to 28997, a 6.8% growth rate as compared to Brazil, Russia, India and China growth rate of -6.29%, -12.2%, 11.5% and 69% respectively, and -25% of bioeconomy world citations. South Africa needs to increase its total citations by a factor of 1.1, 3.5, 4.7 and 20 to produce equivalent volume of quality knowledge similar to Russia, Brazil, India and China respectively. The South African bioeconomy strategy was launched in 2014.A key aspect of the strategy is collaboration (DST 2013). South Africa collaborates well internationally in comparison to the country's international collaboration profile, however of concern is the decline in the number of bioeconomy industry collaboration publications compared to the country's industry collaboration profile. The findings resonates with that of Makhoba and Pouris (2019b) who found that the field of biotechnology in South Africa struggles to produce patents while the publication trend is upward. This could mean that there is increased fragmentation between academic and industrial research in the area of bioeconomy in South Africa. The trend is however similar globally where almost three-fourths of the papers are co-authored by researchers affiliated to a higher education institution, while researchers from private firms are much less visible (Bugge et al 2016).

The above findings have a number of policy implications. Since the launch of the bioeconomy strategy, the average growth of South African bioeconomy related publications increased three-fold. The analysis indicates that the bioeconomy research system can be doubled in size without having to expand the total bioeconomy research system to match that of Russia bioeconomy related publications. However to produce equivalent volume of bioeconomy knowledge production similar to Brazil, India and China, South Africa will require growth of the total research system. With a dedicated bioeconomy strategy in place in South Africa, it will therefore mean that funding for knowledge production under the bioeconomy strategy must be increased substantially. The funding must come from both government and business sector through public-private collaborations. With the current outbreak of a pandemic disease, it would therefore seem that there will be an opportunity for increased availability of resources in particular, on health related research and food and nutrition research, among others, to reduce the long term effects of the pandemic. All these sectors are covered under bioeconomy, however budget availability is not obvious. Therefore with the possible limitation of available resources for bioeconomy in South Africa, other mechanisms to encourage knowledge production in the sector must be investigated. The White Paper on Science, Technology and Innovation in South Africa (DST 2019) emphasis the need for state procurement of innovation, local consumption of domestic innovative products and the establishment of public-private collaborations to encourage innovation. The challenge that is highlighted is the cultivation of a culture of valuing science, technology and innovation in the country and integrating it into government planning and budgeting at the highest level.

In terms of collaborative scientific publications, the bioeconomy strategy in South Africa encourages research in academia that is industry-driven to encourage collaboration between academia and industry. It is therefore recommended that government together with business sector co-fund bioeconomy research in the higher education sector including the science councils, to encourage collaboration across the value chain for government to direct its funding towards academia and for industry to up-scale the research outputs from academia (DST 2002).This in particular may encourage research institutions to undertake research and development with

national and market demand, and thus improve government-industry partnerships. The South Africa's bioeconomy strategy funding model for research to academia and research institutions should therefore be based on the availability of an identified commercial partner and on priorities set by government and industry. In South Africa during 2017/18, 4.2% and 2.2% of business funded research and development supported higher education sector and science councils respectively. A large proportion of government funded research and development supported the higher education sector (58.0%) and the science councils (29.4%) (DSI 2019). In order to reduce the possible fragmentation, all role players must collaborate and share the resources to achieve the goals of the bioeconomy strategy. According to the South African National Development Plan (NDP 2012), research and innovation by universities, science councils, government and business sector have a key role to play in improving South Africa's global competitiveness. Coordination between these different role players is suggested as one of the fundamental issues needing attention.

There is further a need for collaboration between countries, to promote international agreement, collaborative research, regulatory systems, and market incentives for the use of biotechnology products, processes and services (OECD 2009). The increase in South African scientific publications is driven partly by the increase in international research collaborations (NACI 2017). This paper showed international collaboration between South Africa and other countries in bioeconomy research is above the national average. It is however not clear whether there were co-authored publications between South Africa's industry and international industry, or government to government co-authored publications. The study did not look at such relationships as the paper focus on the growth of bioeconomy research in South Africa, that showed research articles are generally published by academia and research institutes in South Africa. Research and development resources from government and the business sector must also be channeled for such collaborative research. In South Africa, proportional foreign funded research and development by sector in 2017/18 was the highest in the higher education (38.3%) followed by the not-for-profit organisations (22.0%). Government and the business sector received 12.0 % and 12.1% of foreign funding for research and development respectively (DSI 2019). It therefore appears that South African government must establish an instrument to attract foreign investment in research and development in bioeconomy in the government and business sectors. The NFF for higher education institutions is an example of such instrument. Such a global perspective on co-authored publications among industries and governments will be crucial in monitoring collaboration between South Africa and other global partners. This may inter alia increase the benefits of the bioeconomy by increasing the number of resources, in addition to local, in bioeconomy and focusing on specific issues of the developing and/or developed world. This may allow for free trade in bioeconomy products and performance standards to support environmental sustainability i.e. through carbon trading systems or environmental taxes, amongst others. Co-authored research publications are also important indicators for sectoral or inter sectoral collaborations. More research however will need to be done to study the impacts of co-authored publications on research commercialisation outputs in bioeconomy. In the European Union, coordination cut across sectors and at multiple levels but it is unclear on the level of coordination at national-level governance systems (Jordan and Schout 2006).

The South African bioeconomy strategy identified several potential indicators beyond the scientific publications as elements of a bioeconomy measurement framework. As indicated by the NACI, the strategy did not clearly articulate the measurement framework to monitor the implementation of the strategy. The NACI proposed a set of indicators that could be used for

monitoring of the strategy. Amongst those indicators proposed, are the findings from this study, that is the measure of the number of South African bioeconomy authored publications and the citations. The findings contributes to the measurement and assessment of the progress of innovation in bioeconomy in South Africa, as well as the contribution that this innovation is making to the development of bioeconomy. The findings further measure the growth of the South Africa's bioeconomoy scientific publications to that of its peers in the BRICS group of countries. However, in order to complete the set of innovation indicators as well as technological advancements for bioeconomy, the NACI recommends that outputs attributed to patents and to innovation by firms in bioeconomy respectively must be investigated. Further, the resources committed to enhancing innovation and technological change in the bioeconomy will need to be assessed. The comparison between research and development expenditures and scientific publications can provide evidence on the structure and productivity of national research systems (OECD 2016). However, the productivity is not always a function of resources available. Makhoba and Pouris (2019b) found that South Africa had the highest research and development efficiency in biotechnology using both patents and publications as indicators, however South Africa had limited resources compared to the BRICS countries.

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