Big Data Analytics for South African National STI Foresight 2030

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Innovation
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INTRODUCTION

Foresight studies have been undertaken for the purpose of investigating in the future of Science, Technology and Innovation (STI) and how these can serve for the improvement of quality of life and creation of wealth, while achieving the goals for sustainable development. A National Foresight exercise has been undertaken for South Africa for identifying STI priorities and strategies towards 2030. The South African National STI Foresight 2030 study aimed at contributing to the following STI objectives of the country:

- advancing the capacity of the national innovation system to contribute to socio-economic development;
- enhancing South Africa's capacity for generating knowledge to produce world class research outputs, as well as innovative products and processes thereafter;
- developing appropriate human capital in the STI sector to meet the needs of society;
- building a world class infrastructure in the STI sector; and
- positioning South Africa as a strategic international R&D and innovation partner and destination.

The Foresight study was commissioned by the Department of Science and Technology (DST) of the Republic of South Africa, and was implemented in cooperation with Non-Zero-Sum Development and the Institute for Statistical Studies and Economics of Knowledge (ISSEK) of the National Research University Higher School of Economics (HSE), Moscow, Russian Federation during 2018 and 2019.

This report presents the results of the Big Data Analysis (BDA) undertaken by the ISSEK HSE. Providing a new evidence-base, Big Data makes precious contributions for Foresight exercises. The types of analyses involved in this study are:

1. Bibliometric analysis of the scientific outputs produced by South Africa. The bibliometric analysis helped to understand South Africa's competences in research with key STI areas focused, scientific capacity within the country and key collaborators across the world and in Africa. The temporal analysis of scientific outputs indicate the mature and emerging areas in South African research landscape

2. Semantic analysis of large document sets was undertaken through the "intelligent Foresight Analytics (iFORA)" system, which is a proprietary tool developed by ISSEK HSE. iFORA uses advanced semantic analysis, machine learning and AI algorithms to integrate diverse information sources including scientific articles, patents, news, grants, analytical reports among the others with the aim of exploring new knowledge on emerging and evolving trends. The iFORA system generated semantic maps for the domain areas and thrusts identified in the South African National STI Foresight exercise. Detailed analyses of maps are provided to describe emerging issues and topics in each domain and the thrusts under them. These are provided in the report with detailed interpretations.

Presenting the results of the analyses, the report begins with a description of the South African research landscape with current trends in research outputs, thematic areas of specialization and scientific partners of South Africa across the world and in the African continent. Dynamic analysis of publications in research outputs indicates the trends in STI related work in South Africa. Following the description of the research landscape and capacity, the next chapter takes a detailed look at each of the STI domains identified by the National STI Foresight 2030 study. The semantic maps generated clearly illustrate the thrusts under each domain and identify emerging topics and issues related to them. This helps to set a development agenda and strategies under the STI domains. Further bibliometric analysis under each domain indicates the research capacity of South Africa, which helps to assess the country's ability to respond to the emerging trends and issues. The study is rounded off with overall conclusions and a detailed description of the methodology in the annex.

ACKNOWLEDGEMENTS

The core team members of ISSEK HSE involved in the South African National STI Foresight 2030 study are: Prof. Ozcan Saritas and Prof. Alexander Sokolov. Mr. Maxim Kotsemir made contributions to the study with bibliometric analysis of the South African scientific landscape through the analysis of South African scientific output. Mr. Pavel Bakhtin of the iFORA Team contributed to the study with the semantic analysis of thousands of documents to identify emerging trends and key topics for South Africa. The present report was co-authored by Prof. Ozcan Saritas, Prof. Alexander Sokolov and Mr. Maxim Kotsemir.

We are grateful to the DST Team, including Dr. Mlungisi Cele, Dr. Petrus Letaba, Mr. Benny Nhlapo, Ms. Thato Dube and other members of the team for their invaluable support, teamwork and hospitality. Collaboration with Mr. Peter Greenwood and Ms. Tina James during the workshops in South Africa was instrumental for the successful completion of this work. We also appreciate the dedication and efforts of the all participants of the Foresight working panels in South Africa. The administrative support provided by Ms. Elena Nasybulina and the DST administrative team is greatly valued by us.

1. RESEARCH LANDSCAPE OF SOUTH AFRICA: CURRENT TRENDS IN RESEARCH OUTPUTS, THEMATIC FOCUS, AND SCIENTIFIC PARTNERSHIPS

This chapter provides a comprehensive analysis of research landscape in South Africa in terms of: level of the country's publication activity and its contribution to the global process of knowledge generation; thematic structure of publications, their scientific specializations; quality of articles measured by citation indicators; similarity of thematic structures of publications; international research collaboration profiles; and finally closeness and relative influence of each country in collaboration with other countries.

The findings presented here should be considered in conjunction with the outputs of the "South Africa Science and Technology Foresight for 2030", which identified seven science and technology domains and thrusts (priorities) associated to them. Matches and mismatches between the priorities and scientific capacity should be assessed in order to develop strategies for supporting some of the critical science and technology areas in order to achieve 2030 visions of the country.

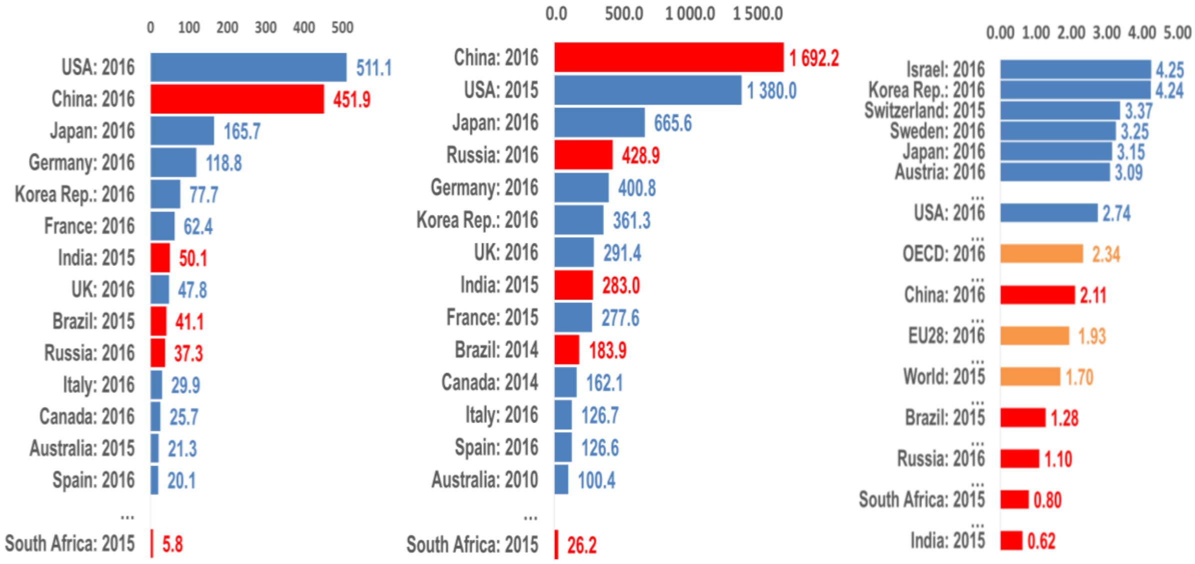
Scopus database was used for analysis with the timespan of 2001-2017[1] that allows demonstrating some of the key trends in the development of research landscape in South Africa. A wide range of bibliometric indicators was used for analysis including citation indicators; indices of structural difference; indicators of scientific collaboration. Among the key outputs produced are:

- publication activity of South Africa, the country's contribution to the global process of knowledge generation;
- thematic structure of publications of South Africa, its scientific specialization, and the quality of articles in the country's specialization areas;
- the similarity of the thematic structure of publications; and
- research collaboration profiles, collaboration closeness, and the dominance level of South Africa in comparison with other countries including BRICS, the United States and the European Union (EU) 28.

Different approaches are used to visualize data in form of illustrative tables and charts. In the analysis, the following types of documents are considered (unless otherwise indicated): articles, conference proceedings, and reviews. A publication is considered to belong to a certain country if at least one of its authors is affiliated with this country.

When South Africa's overall scientific and technological potentials assessed, it is seen that the country still has considerable progress to make. There is an urgent need to increase the R&D intensity of the country. One of the ways of doing this is to increase investments in R&D and the number of active researchers with higher number of publications. On the R&D funding side Figure 1.1 illustrates that South Africa's "Gross Expenditure on Research and Development – GERD" as percentage of GDP is quite low – 0.80.

[1] The year 2018 is not yet complete in scientific databases.



GERD, USD bln PPP Researchers (Full time equivalent, '000) GERD as % of GDP

Figure 1.1 Key R&D expenditures and R&D personnel indicators for BRICS countries in comparison with best benchmark countries in 2016 or last year with available data

Note: Calculated by authors using OECD MSTI (Main Science and technology Indicators database); UNESCO Institute of Statistic database (section "Science, technology and innovation").

The figure above shows that South Africa is far behind leading countries in this respect (EU28 average for this indicator is 1.96 as of year 2015). Regarding publication activity, Figure 1.2 shows number of publications in different countries.

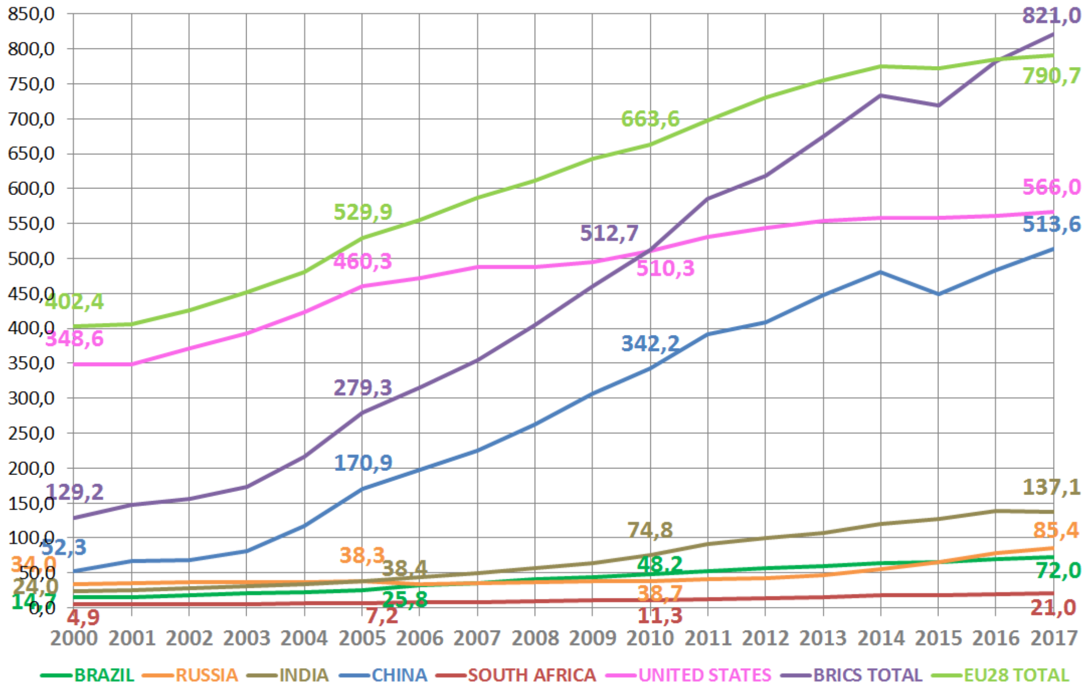


Figure 1.2. Dynamics of publications in Scopus (2000-2017) – (vertical axis indicates 1000 publications)

Note: Data for calculations derived from Scopus SciVal "Benchmarking" Toolbox. Types of publications include articles, reviews, and conference papers.

It is seen that China has made a significant progress in terms of number of publications, whereas increase in the number of publications from South Africa remained rather modest. Further details are shown on Table 1.1, which, in addition, illustrates the share of South Africa in global scientific publication output. In the global ranking on the total number of publications, South Africa is in the top 50 countries.

Table 1.1. Key indicators of publication activity in Scopus in 2000, 2005, 2010 and 2017

Country/ Country group	2000	2005	2010	2017	2000	2005	2010	2017	Growth for 2000-2017, times
	Total no. of publications in Scopus ('000)				Share in global publication output in Scopus				
Brazil	14,7	25,8	48,2	72,0	1,2%	1,5%	2,3%	2,8%	4,90
Russia	34,0	38,3	38,7	85,4	2,8%	2,3%	1,8%	3,3%	2,52
India	24,0	38,4	74,8	137,1	2,0%	2,3%	3,5%	5,3%	5,70
China	52,3	170,9	342,2	513,6	4,3%	10,3%	16,0%	19,9%	9,81
South Africa	4,9	7,2	11,3	21,0	0,40%	0,43%	0,53%	0,81%	4,30
BRICS	129,2	279,3	512,7	821,0	10,7%	16,8%	24,0%	31,8%	6,35
United States	348,6	460,3	510,3	566,0	28,8%	27,6%	23,9%	21,9%	1,62
EU28	402,4	529,9	663,6	790,7	33,2%	31,8%	31,0%	30,6%	1,97
World	**1 210,2**	**1 666,8**	**2 138,9**	**2 582,3**	**100,0%**	**100,0%**	**100,0%**	**100,0%**	**2,13**

Note: Data for calculations derived from Scopus SciVal "Benchmarking" Toolbox. Types of publications include articles, reviews, and conference papers.

Besides the number of publications, it is also important to understand the key areas of competence in scientific work. These are demonstrated by the key subject areas of Scopus (Table 1.2).

Table 1.2. South Africa publication activity by Scopus subject area in 2017

Subjarea	Scopus subject area	Number of SA publications in subject area in 2017	Position of SA in global ranking of countries by number of publications in subject area in 2017	% of SA to Country-leader by number of publications in 2017	Country-leader by number of publications in 2017
AGRI	Agricultural and Biological Sciences	3 197	22	7,0%	USA
ARTS	Arts and Humanities	1 498	13	5,7%	USA
BIOC	Biochemistry, Genetics & Molec. Bio.	1 915	36	2,3%	USA
BUSI	Business, Management and Accounting	964	21	6,8%	USA
CENG	Chemical Engineering	689	36	1,6%	China (since 2009)
CHEM	Chemistry	1 292	35	1,8%	China (since 2007)
COMP	Computer Science	2 063	41	2,6%	China (since 2006)
DECI	Decision Sciences	379	33	4,3%	USA
DENT	Dentistry	28	53	1,0%	USA
EART	Earth and Planetary Sciences	1 397	26	4,2%	China (since 2015)
ECON	Economics, Econometrics and Finance	580	22	5,1%	USA
ENER	Energy	800	34	2,4%	China (since 2005)
ENGI	Engineering	2 513	42	1,6%	China (since 2007)
ENVI	Environmental Science	1 948	25	5,5%	USA
HEAL	Health Professions	353	29	2,7%	USA
IMMU	Immunology and Microbiology	852	24	4,2%	USA
MATE	Materials Science	1 484	38	1,5%	China (since 2007)
MATH	Mathematics	1 212	41	2,3%	China (since 2012)
MEDI	Medicine	6 010	28	2,8%	USA
MULT	Multidisciplinary	238	38	2,0%	China (since 2015)
NEUR	Neuroscience	302	40	1,2%	USA
NURS	Nursing	375	26	2,7%	USA
PHAR	Pharmacology, Toxicology & Pharma.	593	32	3,3%	USA
PHYS	Physics and Astronomy	2 159	38	2,6%	China (since 2013)
PSYC	Psychology	570	29	2,2%	USA
SOCI	Social Sciences	3 666	16	5,9%	USA
VETE	Veterinary	65	24	6,3%	USA
Total	**All publications**	**22 051**	**29**	**3,7%**	**USA**

Note: Authors' calculations from SCImago journal and country rank database (based on Scopus). Types of publications include articles, reviews, and conference papers. SCImago Data was updated at June 2018.

Analysis of Table 1.2 indicates that South Africa lags behind other BRIC countries in global ranking on number of publications in Scopus. The country is placed usually below 20th in 27 Scopus subject areas. Among the "strongest" subject areas for South Africa are: "Agricultural and Biological Sciences" (22nd position and 7.0% of the global leader); "Business, Management and Accounting" (21st and 6.8%); "Veterinary" (24th and 6.3%); "Social sciences" (16th and 5.9%); "Arts and humanities" (13th and 5.7%).

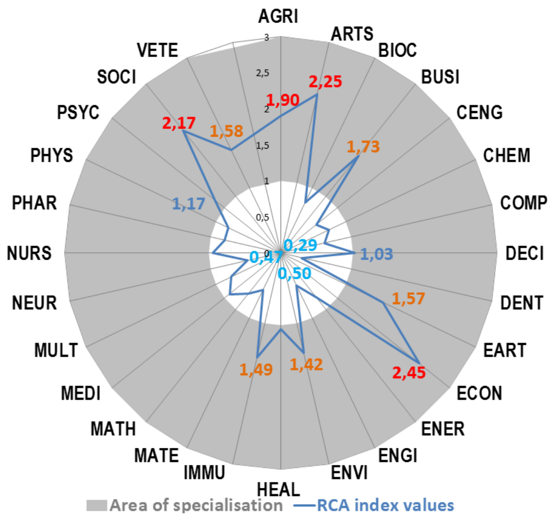


Figure 1.3. Specialization areas of South Africa by Scopus subject areas for 2013 - 2017[2]

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

In order to better illustrate the key areas of specializations, a further analysis was undertaken using Relative Comparative Advantage, or Revealed Comparative Advantage (RCA) index, which is used to measure the degree of scientific specialization of a country in a given subject area. Subject areas where RCA index value is higher than 1.00 are areas of the research specialization of a given country. Subject areas where the value of the RCA index is significantly higher than 1.00 (i.e. above 1.50 or 2.00) can be attributed to the key areas of the scientific specialization of the country.[3] Figure 1.3 illustrates the specialization areas of South Africa in Scopus subject areas.

The figure illustrates that South Africa has significant specialization in the areas of “ECON - Economics, Econometrics and Finance” (RCA: 2.45); “ARTS - Arts and Humanities” (RCA: 2.25); “SOCI - Social Sciences” (RCA: 2.17); and “AGRI - Agricultural and Biological Sciences” (RCA: 1.90). Further scientific specialization is also observed in “BUSI – Business, Management and Accounting”; “VETE – Veterinary”; “EART – Earth and Planetary Sciences”; “IMMU – Immunology and Microbiology”; “ENVI – Environmental Science”; and “DECI – Decision Sciences” (1.0<RCA<1.80). Low specialization is observed in some of the key areas like “ENGI – Engineering”; “NEUR – Neuroscience”; and “COMP – Computer Science” (RCA<1.0).

[2] 27 Scopus subject areas are abbreviated as follows: AGRI – Agricultural and Biological Sciences; ARTS – Arts and Humanities; BIOC – Biochemistry, Genetics and Molecular Biology; BUSI – Business, Management and Accounting; CENG – Chemical Engineering; CHEM – Chemistry; COMP – Computer Science; DECI – Decision Sciences; DENT – Dentistry; EART – Earth and Planetary Sciences; ECON – Economics, Econometrics and Finance; ENER – Energy; ENGI – Engineering; ENVI – Environmental Science; HEAL – Health Professions; IMMU – Immunology and Microbiology; MATE – Materials Science; MATH – Mathematics; MEDI – Medicine; MULT – Multidisciplinary; NEUR – Neuroscience; NURS – Nursing; PHAR – Pharmacology, Toxicology and Pharmaceutics; PHYS – Physics and Astronomy; PSYC – Psychology; SOCI – Social Sciences; VETE – Veterinary.
Source: Authors’ calculations from data taken from the Scopus database. Types of publications include articles, reviews, and conference papers. Data is current as of September 2016.

[3] For a given country (j) and a given subject area (i) Revealed comparative advantages index (RCA) index is calculated as follows: $RCA_{subjarea\ i\ country\ j} = \frac{Share_{subjarea\ i\ country\ j}}{Share_{subjarea\ i\ world}}$

where $Share_{subjarea\ i\ country\ j}$ – is the share of publications on subject area i (i = 1, … , 27) in the total number of publications of a specific country j in the Scopus database; - $Share_{subjarea\ i\ world}$ - is the share of publications on subject area i (i = 1, … , 27) in the global number of publications in the Scopus database.

Considering the science and technology priority domains and priorities for South Africa, particularly Engineering and Computer Sciences areas need immediate attention for the development of the scientific capacity.

Figure 1.4 shows the thematic structure of publications in South Africa based on the shares of publications in 27 Scopus subject areas in the total number of publications of South Africa in Scopus. Key areas of research of South Africa in Scopus are Medicine; Social sciences; and Agricultural and biological sciences.

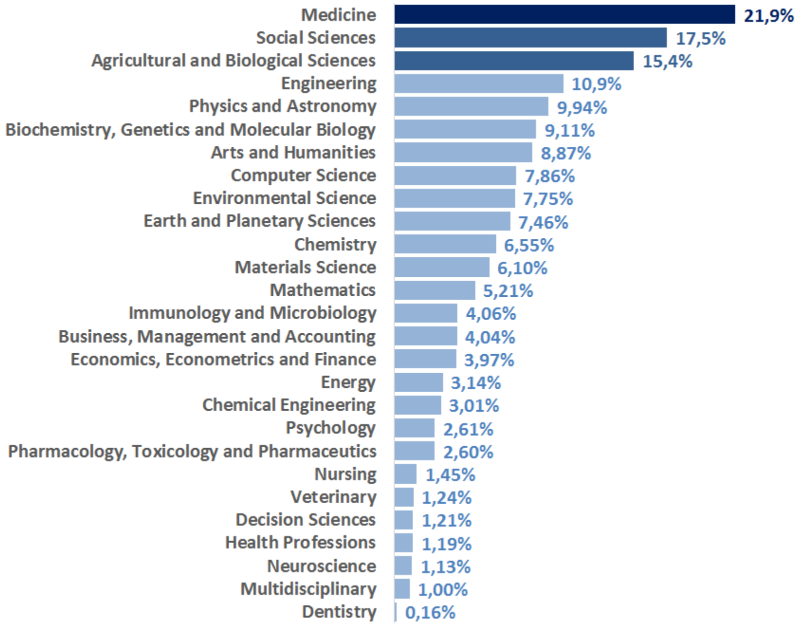


Figure 1.4. Subject structure of publications of South Africa in Scopus for 2013 – 2017

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Figure 1.5 further analyses the subject areas by considering the quality of publications in those areas.

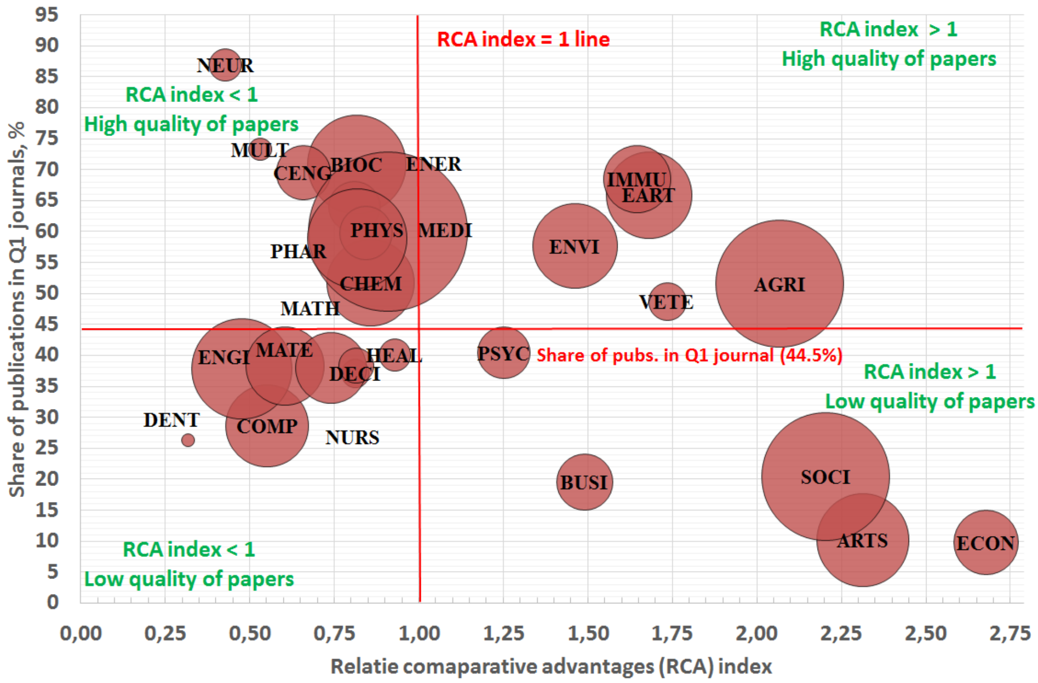


Figure 1.5. Areas of specialization vs. quality of publications of South Africa in Scopus in 2011 – 2015

Notes: Bubble size (square) is set as the number of publications for 2011 – 2015 in a given subject area. Data for calculations derived from Scopus SciVal "Benchmarking" Toolbox. Types of publications include articles, reviews, and conference papers.

In Figure 1.5, the quality of publications is measured based on whether they are published in Q1 journals. The subject areas with 45% or more of total such publications are considered to be 'high quality'. **The degree of specialization is indicated with the RCA scores. If the RCA score is higher than 1.0, there is a high degree of specialization. In the figure, the bubble size is determined by the number of publications from 2011 to 2017 in a given subject area. Overall, it is seen that the subject areas related to Agriculture, Environment, Immunology, and Earth sciences produce high quality output with high degree of specialization. These are clearly among the strengths of South Africa. Medicine is the next area, where South Africa indicates strong potentials if further invested. As noted earlier, areas related to Mathematics, Engineering and Computer science are rather poor and need strong support, if the country is to address Grand Challenges, where these scientific areas are the key enablers of development. Research in Business, Economy, and Social sciences clearly is in need for higher quality output to be competitive nationally and globally. Figure 1.6 shows the dynamics of growth of South African publications in common for BRICS STI priority areas from year 2000 to 2017.**

As the figure illustrates, South Africa makes some progress in almost all scientific areas. However, considering the low number of publications, the figures are far from ideal for a significant progress at the national and global levels. The biggest improvement is observed in "Renewable energy sources" (24 times since year 2000), which is meaningful considering the climate change and growing demand for sustainable energy. Similarly, the emphasis on "Information and Communication Technologies" is also growing. Despite of this growth, the earlier analysis showed that there still remains a substantial progress to be made in this area. "Transport" is an area, which appears to be receiving more attention with 10 times of growth. However, the number of publications is extremely low in order to interpret this progress as significant. In terms of the share of scientific work in South Africa as percentage of total work in the world, "Food security and sustainable agriculture" area represents over 1%, like other areas including "Climate change, environmental protection and disaster management", and "Water resources". Considering the priority areas in the S&T Foresight 2030, these advancements are certainly crucial. **It is also noteworthy that "Space systems and astronomical observations" represent over 1% of the global scientific output as of 2017. This area is also a key for achieving 2030 visions. [need to consider these in new plan]**

Area	South Africa				
	N. of publications		Growth, times	Share in the world	
	2000	2017		2000	2017
1. Information and communication technologies	167	2 053	12,29	0,21%	0,57%
2. Nanotechnology and new materials	304	1 470	4,84	0,24%	0,48%
3. Advanced manufacturing and robotics	300	1 701	5,67	0,20%	0,44%
4. Space systems and astronomical observations	105	448	4,27	0,51%	1,06%
5. Transport systems	7	74	10,57	0,12%	0,35%
6. Energy efficiency and energy saving	39	457	11,72	0,16%	0,64%
7. Nuclear energy	8	32	4,00	0,18%	0,24%
8. Renewable energy resources	18	444	24,67	0,45%	0,99%
9. Search, exploration, development and mining of minerals	219	556	2,54	0,68%	0,97%
10. Climate change, environmental protection and disaster management	502	1 994	3,97	0,85%	1,13%
11. Water resources	252	586	2,33	0,91%	1,04%
12. Food security and sustainable agriculture	560	1 315	2,35	1,27%	1,30%
13. Healthcare and medicine	1 075	4 583	4,26	0,32%	0,77%
14. Biotechnology	331	951	2,87	0,33%	0,59%
Total (all publications in Scopus)	**4 842**	**21 120**	**4,36**	**0,40%**	**0,80%**

Figure 1.6. Research potentials of South Africa in Scopus in common for BRICS countries STI priority areas in 2000 and 2017

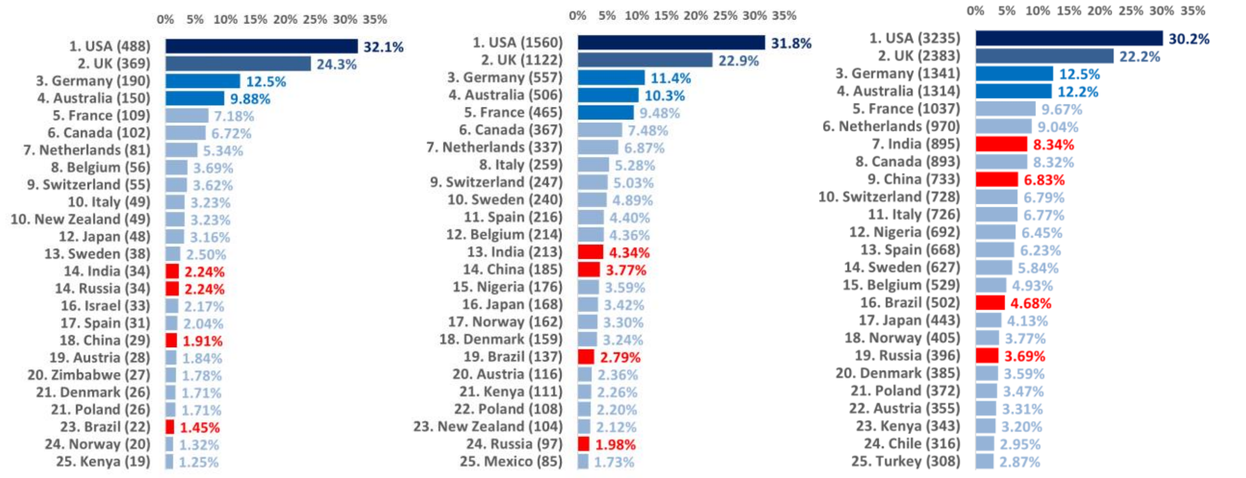
Note: Correspondence between priority areas and Scopus subject Areas is shown in in Table A.1 in Appendix. Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Another important aspect of scientific work is 'international collaboration', which represents joint research and knowledge exchange between countries. Table 1.3 illustrates the global scientific partners of South Africa. As the table illustrates, the United States, Australia, and five leading European countries (incl. United Kingdom, Germany, France and the Netherlands) are among the top scientific partners of South Africa. These partners indicate leading positions in internationally collaborated publications. India and China are among the BRICS countries, which South Africa is intensively collaborating in top 10 partner countries. Among the others South Africa's partnerships with other African countries including Nigeria, Kenya and Zimbabwe are noteworthy. Figure 1.8 illustrates the dynamics of these partnerships across time. Although the top 5 collaborators remained the same since 2000, new scientific partners are emerging for South Africa. For instance, the share of BRICS counties as percentage of total partnerships has increased significantly from 7.84% in 2000 to 12.88% in 2010, and finally 23.54% in 2017. Meanwhile, new partnerships have been established with countries like Chile, Mexico and Turkey. Finally, Table 1.4 presents the thematic structure of internationally collaborated publications of South Africa in years 2000, 2010 and 2017 by Scopus subject area. It is seen that subject areas like Business, Management and Accounting; Health Professions; Decision Sciences; Nursing; and Arts and Humanities are gaining momentum in terms of the growth of their share in total number of publications.

Table 1.3. Scientific partners of South Africa in South Africa in Scopus in 2017

Country	Number of joint publications with a country			Growth of joint papers 2017 to 2010, times	Share of a country in all internationally collaborated punblications (ICPs) of SAR		
	2000	2010	2017		2000	2010	2017
All ICPs of SAR	1518	4906	10 729	7,07	100,0%	100,0%	100,0%
1. United States	488	1560	3235	6,63	32,15%	31,80%	30,15%
2. United Kingdom	369	1122	2383	6,46	24,31%	22,87%	22,21%
3. Germany	190	557	1341	7,06	12,52%	11,35%	12,50%
4. Australia	150	506	1314	8,76	9,88%	10,31%	12,25%
5. France	109	465	1037	9,51	7,18%	9,48%	9,67%
6. Netherlands	81	337	970	11,98	5,34%	6,87%	9,04%
7. India	34	213	895	26,32	2,24%	4,34%	8,34%
8. Canada	102	367	893	8,75	6,72%	7,48%	8,32%
9. China	29	185	733	25,28	1,91%	3,77%	6,83%
10. Switzerland	55	247	728	13,24	3,62%	5,03%	6,79%
11. Italy	49	259	726	14,82	3,23%	5,28%	6,77%
12. Nigeria	12	176	692	57,67	0,79%	3,59%	6,45%
13. Spain	31	216	668	21,55	2,04%	4,40%	6,23%
14. Sweden	38	240	627	16,50	2,50%	4,89%	5,84%
15. Belgium	56	214	529	9,45	3,69%	4,36%	4,93%
16. Brazil	22	137	502	22,82	1,45%	2,79%	4,68%
17. Japan	48	168	443	9,23	3,16%	3,42%	4,13%
18. Norway	20	162	405	20,25	1,32%	3,30%	3,77%
19. Russian Federation	34	97	396	11,65	2,24%	1,98%	3,69%
20. Denmark	26	159	385	14,81	1,71%	3,24%	3,59%
21. Poland	26	108	372	14,31	1,71%	2,20%	3,47%
22. Austria	28	116	355	12,68	1,84%	2,36%	3,31%
23. Kenya	19	111	343	18,05	1,25%	2,26%	3,20%
24. Chile	13	70	316	24,31	0,86%	1,43%	2,95%
25. Turkey	10	60	308	30,80	0,66%	1,22%	2,87%
26. Portugal	4	68	305	76,25	0,26%	1,39%	2,84%
27. Zimbabwe	27	72	291	10,78	1,78%	1,47%	2,71%
28. Finland	16	67	281	17,56	1,05%	1,37%	2,62%
29. Czech Republic	8	74	276	34,50	0,53%	1,51%	2,57%
29. New Zealand	49	104	276	5,63	3,23%	2,12%	2,57%
31. Argentina	9	83	254	28,22	0,59%	1,69%	2,37%

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.



2000 2010 2017

Figure 1.8. Top 25 scientific partners of South Africa in Scopus in years 2000, 2010 and 2017

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

Table 1.4. Thematic structure of internationally collaborated publications of South Africa in years 2000, 2010 and 2017 by Scopus subject area

Scopus Subject area	Number of internationally collaborated publications (ICPs) in subject area			Growth of ICPs 2017 to 2010, times	Share of a subject area in all ICPs of SAR			Growth of share of subject area 2017 to 2010, times
	2000	2010	2017		2000	2010	2017	
	1515	4903	10 776		100.0%	100.0%	100.0%	
Medicine	329	1354	2822	8.58	21.72%	27.62%	26.19%	1.21
Agricultural and Biological Sciences	336	1069	1881	5.60	22.18%	21.80%	17.46%	0.79
Physics and Astronomy	216	566	1465	6.78	14.26%	11.54%	13.60%	0.95
Social Sciences	122	490	1218	9.98	8.05%	9.99%	11.30%	1.40
Engineering	124	449	1151	9.28	8.18%	9.16%	10.68%	1.30
Biochemistry, Genetics and Molecular Biology	207	551	1111	5.37	13.66%	11.24%	10.31%	0.75
Environmental Science	114	416	1058	9.28	7.52%	8.48%	9.82%	1.30
Earth and Planetary Sciences	218	511	936	4.29	14.39%	10.42%	8.69%	0.60
Materials Science	101	291	791	7.83	6.67%	5.94%	7.34%	1.10
Chemistry	115	369	693	6.03	7.59%	7.53%	6.43%	0.85
Computer Science	60	248	683	11.38	3.96%	5.06%	6.34%	1.60
Mathematics	100	272	640	6.40	6.60%	5.55%	5.94%	0.90
Immunology and Microbiology	88	374	562	6.39	5.81%	7.63%	5.22%	0.90
Arts and Humanities	23	180	387	16.83	1.52%	3.67%	3.59%	2.37
Energy	28	98	382	13.64	1.85%	2.00%	3.54%	1.92
Chemical Engineering	34	169	329	9.68	2.24%	3.45%	3.05%	1.36
Business, Management and Accounting	11	82	313	28.45	0.73%	1.67%	2.90%	4.00
Psychology	18	122	311	17.28	1.19%	2.49%	2.89%	2.43
Pharmacology, Toxicology and Pharmaceutics	47	143	290	6.17	3.10%	2.92%	2.69%	0.87
Economics, Econometrics and Finance	33	69	238	7.21	2.18%	1.41%	2.21%	1.01
Neuroscience	24	62	177	7.38	1.58%	1.26%	1.64%	1.04
Multidisciplinary	15	47	175	11.67	0.99%	0.96%	1.62%	1.64
Health Professions	8	50	174	21.75	0.53%	1.02%	1.61%	3.06
Nursing	10	79	171	17.10	0.66%	1.61%	1.59%	2.40
Veterinary	33	80	146	4.42	2.18%	1.63%	1.35%	0.62
Decision Sciences	7	32	131	18.71	0.46%	0.65%	1.22%	2.63
Dentistry	7	11	8	1.14	0.46%	0.22%	0.07%	0.16

Note: Data for calculations derived from the Scopus database. Types of publications include articles, reviews, and conference papers.

2. SEMANTIC ANALYSIS OF STI DOMAINS AND THRUSTS

The National STI Foresight 2030 study identified seven STI domains and thrusts associated to them. STI domains are defined as fairly broad but bounded areas, related to STI as well as to a societal need or issue. The Foresight study identified several thrusts for each of the STI domains. Thrusts are considered as STI-related priority areas, which indicate what South Africa wishes to achieve with the time horizon of 2030. Throughout the Foresight process, a number of STI areas were identified. These were prioritized using a set of criteria related to their (i) potentials for new impact, (ii) association to global and STI trends, and (iii) contribution to socio-economic development. As a result of online and offline consultations with the stakeholders of the STI system in South Africa, first, eight STI domains were selected. The number was then reduced to seven as two of the domains were merged. Then thrusts were determined through the following stages of the Foresight study. First, a long list of thrusts was proposed through a Foresight workshop. Then, these were shortlisted using a new set of prioritization criteria by considering their importance and feasibility. The importance criteria included the (i) socio-economic impact; (ii) new impact; and (iii) strategic value of each thrust. The feasibility criteria included (i) availability of required knowledge and expertise; (ii) availability of institutional capacity; (iii) availability of infrastructure; (iv) required policy and regulatory environment in place; (v) social and ethical acceptability; (vi) amount of relevant funding currently allocated and; (vii) ease of addressing barriers and obstacles. In total of 25 thrusts were identified under seven STI domains. These are:

1. CIRCULAR ECONOMY
    a. CE1: Reduce, reuse and recycle waste
    b. CE2: Ensuring sustainable water, energy and food (agriculture) security
    c. CE3: Low-carbon and climate-resilient economy
    d. CE4: Smart connectivity and mobility in communities

2. HIGH-TECH INDUSTRY
    a. HT1: Enabling small business to adopt high tech
    b. HT3: New thinking for new industries
    c. HT4: New thinking for old industries

3. NUTRITION SECURITY FOR A HEALTHY POPULATION
    a. NU1: Zero impact agriculture
    b. NU2: Use and acceptance of modern biotechnology
    c. NU3: Personalized information for healthy nutrition for all
    d. NU4: Precision and big data in agri-businesses

4. THE OPPORTUNITIES, THREATS AND IMPACT OF ICTs, INCLUDING SMART SYSTEMS, ON SOCIETY
    a. IT1: Checks and balances for a digital future
    b. IT2: ICT infrastructure and Internet access
    c. IT3: Big data, data analytics and decision support
    d. IT4: Smart and sustainable municipal service delivery

5. HEALTH TECHNOLOGY TO PREVENT AND TREAT ILL-HEALTH, AND ADVANCE WELL-BEING FOR THOSE WHO ARE MARGINALIZED
    a. HE1: Optimization of health systems
    b. HE2: Improving the quality of healthcare
    c. HE3: Digitization of health systems

6. SUSTAINABLE ENERGY TECHNOLOGIES FOR THE MARGINALIZED
    a. EN1: Clean, affordable and sustainable energy for all
    b. EN2: Renewable energy sources and technologies
    c. EN3: Energy efficiency solutions for industry plus household use
    d. EN4: Distributed energy generation and storage

7. EDUCATION FOR THE FUTURE
    a. ED1: Skills for the 4th Industrial Revolution
    b. ED2: Inclusive innovation and development
    c. ED3: Curriculum development 2030

The following sections present the results of the semantic analysis with the iFORA system for each domain areas. Detailed analyses of maps are provided to describe emerging issues and topics in each domain and the thrusts under them.

2.1. CIRCULAR ECONOMY DOMAIN

Overall description of the domain

The Circular Economy domain is concerned with the generation of products which are restorative and regenerative by design, and which circulate through the economy repeatedly, thereby minimizing waste. This includes the conversion of biological and non-biological waste into new resources and materials as well as the restoration and protection of biodiversity with further implications for rural areas.

Overview of research potential of South Africa in "Circular economy" domain

Figure 2.1.1 shows that there is a growing scientific emphasis on the Circular Economy domain in South Africa. The number of publications has been growing steadily as well as the share of South Africa in the global scientific output in this domain.

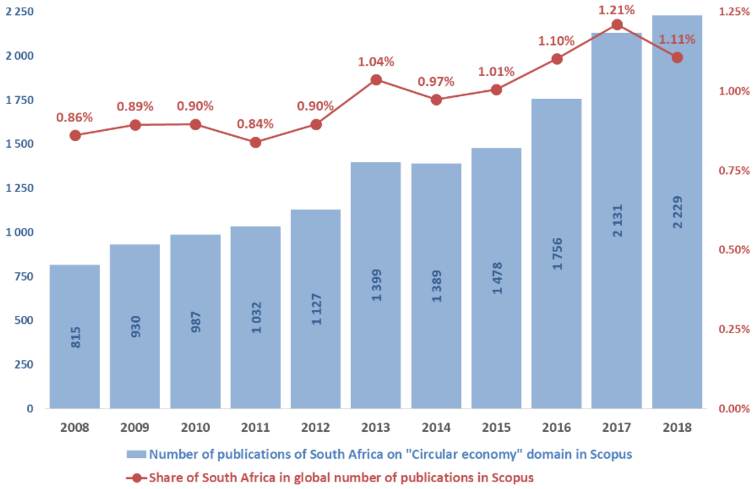


Figure 2.1.1. Dynamics of publications of South Africa in "Circular economy" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.1.2 shows the leading countries in the Circular Economy domain.

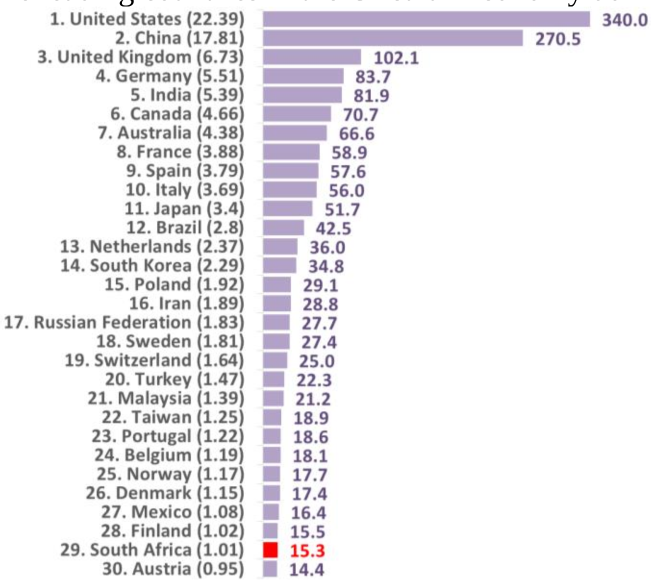


Figure 2.1.2. Leading countries by number of publications ('000) in "Circular economy" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Australia, Germany and France (Table 2.1.1). Nigeria, Zimbabwe, Kenya, Namibia and Ethiopia are among the African scientific partners of South Africa.

Table 2.1.1. Key partner countries of South Africa in internationally collaborated publications in "Circular economy" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	2058	25.98%
United Kingdom	1730	21.84%
Australia	1126	14.22%
Germany	845	10.67%
France	753	9.51%
Netherlands	613	7.74%
Canada	548	6.92%
Sweden	476	6.01%
India	437	5.52%
Nigeria	433	5.47%
Spain	358	4.52%
China	352	4.44%
Italy	349	4.41%
Switzerland	329	4.15%
Norway	311	3.93%
Zimbabwe	292	3.69%
Belgium	281	3.55%
New Zealand	260	3.28%
Kenya	240	3.03%
Japan	237	2.99%
Brazil	200	2.53%
Denmark	199	2.51%
Austria	187	2.36%
Portugal	174	2.20%
Finland	162	2.05%
Namibia	157	1.98%
Ethiopia	139	1.76%
Czech Republic	132	1.67%
Botswana	127	1.60%
Tanzania	123	1.55%
Ghana	111	1.40%
Poland	111	1.40%
Argentina	102	1.29%
Mexico	95	1.20%
Iran	94	1.19%
Malaysia	92	1.16%
Uganda	91	1.15%
Chile	88	1.11%
Russian Federation	88	1.11%
Thailand	80	1.01%
Malawi	72	0.91%
Zambia	71	0.90%
Cameroon	67	0.85%
Saudi Arabia	67	0.85%
Mozambique	65	0.82%
Israel	64	0.81%
Ireland	61	0.77%

Turkey	59	0.74%
Hungary	55	0.69%
Egypt	54	0.68%
Indonesia	52	0.66%
South Korea	50	0.63%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.1.2 shows the leading organizations in South Africa publishing in the domain of Circular Economy with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.1.2. Leading organizations of South Africa by number of publications in "Circular economy" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of Cape Town	2127	8.89%
University of KwaZulu-Natal	1808	7.56%
Universiteit Stellenbosch	1775	7.42%
Universiteit van Pretoria	1731	7.24%
University of Witwatersrand	1271	5.31%
North-West University	910	3.80%
The Council for Scientific and Industrial Research	874	3.65%
University of Johannesburg	867	3.62%
Rhodes University	862	3.60%
University of the Free State	624	2.61%
Nelson Mandela Metropolitan University	536	2.24%
Tshwane University of Technology	495	2.07%
University of South Africa	414	1.73%
University of the Western Cape	403	1.68%
Agricultural Research Council, Pretoria	309	1.29%
University of Fort Hare	300	1.25%
University of Venda for Science and Technology	285	1.19%
South African National Biodiversity Institute	278	1.16%
Cape Peninsula University of Technology	258	1.08%
South African National Parks	219	0.92%
Marine and Coastal Management	214	0.89%
Durban University of Technology	207	0.87%
University of Limpopo	199	0.83%
South African Institute for Aquatic Biodiversity	181	0.76%
South African Environmental Observation Network	141	0.59%
South African Medical Research Council	135	0.56%
University of Zululand	116	0.48%
Vaal University of Technology	113	0.47%
International Water Management Institute, Pretoria	111	0.46%
Human Sciences Research Council of South Africa	95	0.40%
Plant Protection Research Institute, Pretoria	90	0.38%
Council for Geoscience	80	0.33%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	76	0.32%
Kruger National Park	72	0.30%
Ezemvelo KZN Wildlife	68	0.28%
Endangered Wildlife Trust	64	0.27%
South African Water Research Commission	55	0.23%
National Research Foundation	54	0.23%
Central University of Technology, Free State	53	0.22%
South African Weather Service	53	0.22%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Circular economy" domain

This section describes the "Circular Economy" STI domain and its thrusts based on the results of the semantic analysis produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Figure 2.1.3 shows the entire domain of the Circular Economy (CE) with its clusters and interrelations to each other. A detailed analysis of Figure 2.1.3 provides an overview of CE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.1.3. In the following sections network maps are given to illustrate these thrusts and further issues emerging under each of them.

Table 2.1.3. "Circular Economy" thrusts and topics

Circular Economy Thrusts	**Topics emerging under each thrust**
CE1: Reduce, reuse and recycle waste	Waste reduction (Fig. 2.1.4)
	Waste recycling and sustainable strategy (Fig. 2.1.5)
CE2: Ensuring sustainable water, energy and food (agriculture) security	Water resources (Fig. 2.1.6)
	'Water management' and 'flood risk and extreme weather' (Fig. 2.1.7)
	Agricultural water use (Fig. 2.1.8)
	'Water security' and 'Food security' (Fig. 2.1.9)
	Precision framing and farm efficiency (Fig. 2.1.10)
	Agricultural policy (Fig. 2.1.11)
CE3: Low-carbon and climate resilient economy	Economic impact of sustainability (Fig. 2.1.12)
	'Energy efficiency' and 'Renewable energy' (Fig. 2.1.13)
	Low carbon and low emissions (Fig. 2.1.14)
	Climate change (Fig. 2.1.15)
	'Biodiversity conservation' and 'Land use' (Fig. 2.1.16)
	African environmental policy (Fig. 2.1.17)
CE4: Smart connectivity and mobility in communities, supporting the circular economy	Green transport (Fig. 2.1.18)

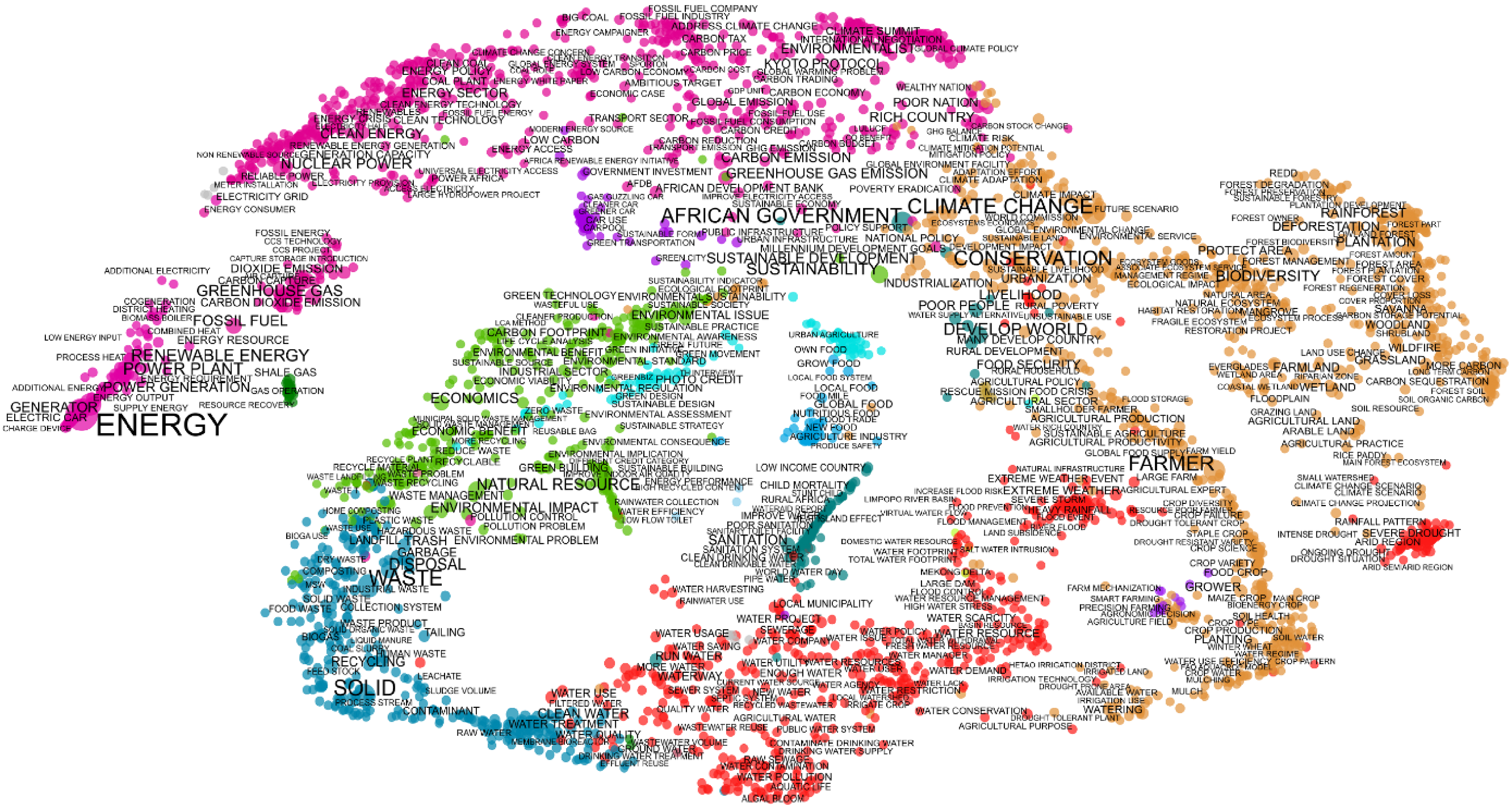


Figure 2.1.3. "Circular economy" domain full semantic map for 2014-2018

CE1: Reduce, reuse and recycle waste

This thrust is concerned with the development and deployment of performance improvements in "waste management". It is considered that development of efficient and effective waste management systems will make a significant contribution for strengthening the sustainable use of resources and thus reducing the environmental impact of waste. The analysis of the thrust through the iFORA system yielded two important action points. The first one is related to "waste reduction" and the second is "waste recycling and sustainable strategy". Issues around both action points are shown in the maps below (Figures 2.1.4. and 2.1.5).

Figure 2.1.4. "Waste reduction"

The first step in achieving breakthrough progress in CE is waste reduction. This covers the issues of garbage disposal, waste collection system, landfills and recycling solid waste. Points also arise regarding different types of waste such as food waste, industrial waste, human waste, organic waste, dry waste and hazardous waste, all of which need to be treated and recycled in a certain way. Energy generation through Biogas production appears to be a promising solution in terms of using waste.

Indeed, besides reducing waste and recycling and reusing them, it is also important to develop strategies for sustainable waste recycling.

Figure 2.1.5. "Waste recycling and sustainable strategy"

Figure 3 shows the whole set of issues for the development of sustainable waste recycling strategies. There are a number of areas, which require action under this category. These include strategies for increasing efficiency such as making buildings greener and making them more sustainable, as well as collecting rainwater and using low flow toilets for increased water efficiency. Better management of different waste categories such as solid, plastic and hazardous, through waste reduction and recycling are also mentioned under this thrust.

CE2: Ensuring sustainable water, energy and food (agriculture) security

iFORA analysis yielded six important areas under this thrust:

1. Water resources
2. 'Water management' and 'Flood risk and extreme weather'
3. Agricultural water use
4. 'Water security' and 'Food security'

5. Precision framing and farm efficiency
6. Agricultural policy

The water resources category represents issues around water usage, operation of water resources and their management by municipalities, water pollution and water treatment through techniques like membranes and filtration (Figure 2.1.6). Water harvesting and rainwater use also come as important areas under this cluster.

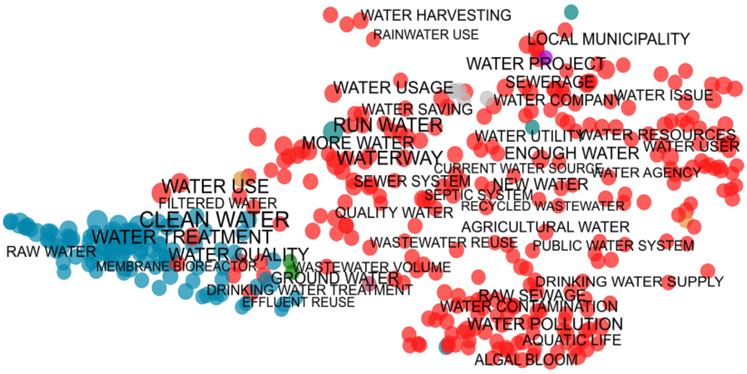


Figure 2.1.6. "Water resources"

Management of water resources is strongly linked to the weather conditions and flood (Figure 2.1.7). Extreme weather events, rainfalls and floods directly affect the availability of water. Unbalanced supply of water makes water management critical. There is a need to manage water when it is abundant as well as when it is not available. Therefore, besides introducing water flood management systems, there is a need to develop irrigation technologies for agricultural water use, as well as research and development on drought resistant plants.

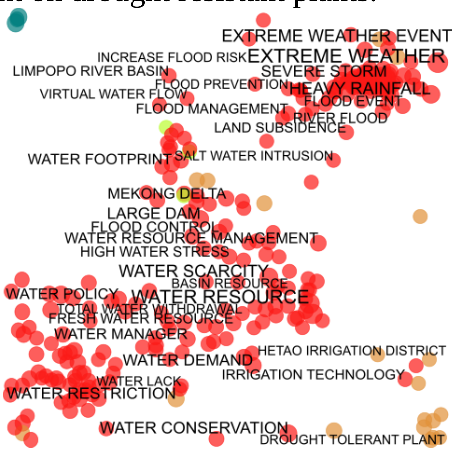


Figure 2.1.7. "Water management" and "flood risk and extreme weather"

Under water security thrusts a particular emphasis emerges on agricultural water use. Here a number of issues arise regarding planting, crop water and water use efficiency as well as development of irrigation technologies and efficient watering (Figure 2.1.8).

Figure 2.1.8. "Agricultural water use"

The water and food nexus emerge as an important issue. Under water security, the use of water for sanitation is highlighted with all other issues related that such as poor sanitation, sanitation systems, and sanitary toilet facilities. Water security in terms of accessing clean drinkable water is also mentioned in this category and linked further to sanitation and low water access in rural Africa and associated child mortality (Figure 2.1.9). Also in the right side of the figure, food security is mentioned in association to issues like growing food, local and urban food production systems as well as increasing nutrition and development of the agriculture industry with safe food production.

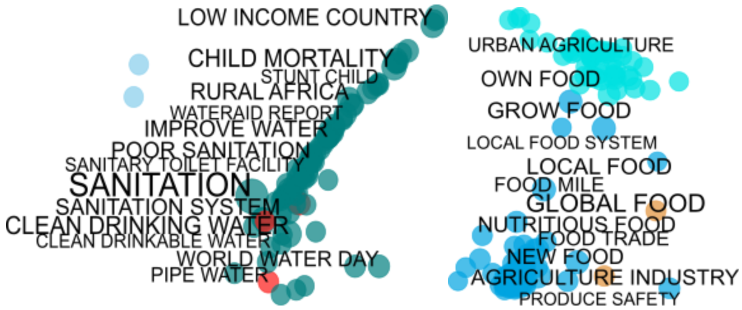


Figure 2.1.9. “Water security” (left) and “Food security” (right)

Among the technologies emerging with potential contributions to sustainable water, energy and food (agriculture) security is precision farming and other technologies for increasing farm efficiency. Smart farming and farm mechanization technologies also emerge as important areas for technological development. Increasing crop diversity, developing drought tolerant crops, and further research in crop type and production appear to be areas for improving farm efficiency. Besides crops, soil health is also addressed as an important topic in this category (Figure 2.1.10).

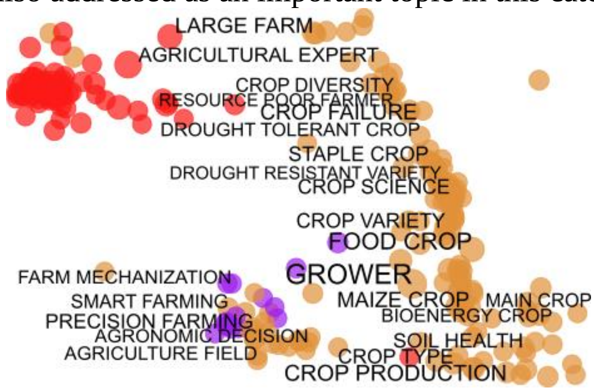


Figure 2.1.10. “Precision farming and farm efficiency”

Indeed, technologies are not solely enough for achieving sustainable water, energy and food security. There should be necessary agricultural policy in place for managing agricultural practices, providing food security, and a more balanced development. Industrialization and urbanization also emerge as important and associate areas to the agricultural policy topic (Figure 2.1.11).

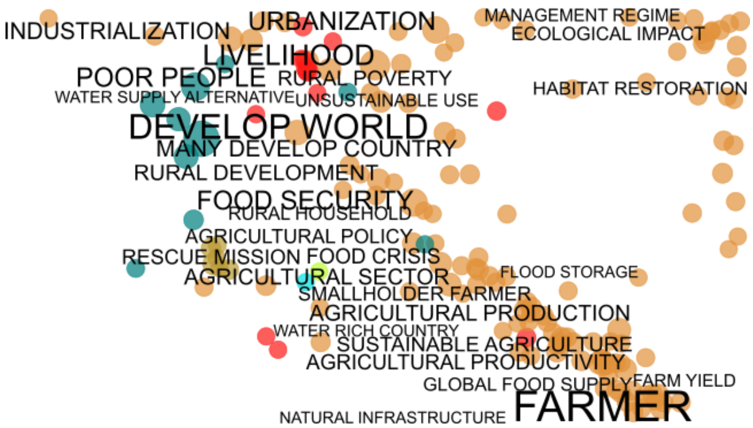


Figure 2.1.11. “Agricultural policy”

CE3: Low-carbon and climate resilient economy

The third thrust under CE domain is concerned with the low-carbon and climate resilient economy. The iFORA system identified six important topics under this thrust, including:

1. Economic impact of sustainability
2. ‘Energy efficiency’ and ‘Renewable energy’
3. Low carbon and low emissions
4. Climate change
5. ‘Biodiversity conservation’ and ‘Land use’
6. African environmental policy

Economy plays a critical role for shifting to a low-carbon society and creating a more resilient economy under the effects of climate change. Reduction or carbon footprint, implementing greener initiatives and technologies, introduction of life cycle analysis and cleaner production are the key principles of this new economy. In order to achieve these, businesses need to be ‘greener’ with more sustainable design of products, processes and services, and zero waste. Reusable bag emerges as a specific issue in this category, as high amount of plastic bag use appears to be an important problem (Figure 2.1.12).

Figure 2.1.12. “Economic impact of sustainability”

Efficient energy use and increasing use of renewables are also detected as important topics under low carbon and climate resistant economy. Under energy efficiency, the reduction of fossil fuel use, and greenhouse gas emissions appear to be the key challenges for South Africa. Development of low energy input technologies, cogeneration, district heating and introduction of electric cars and necessary infrastructure for charging them appear to be important areas. Nuclear power is still on the agenda for South Africa together with coal power plants. The role and share of these in the energy mix should be determined towards the goals for higher energy efficiency and renewables (Figure 2.1.13).

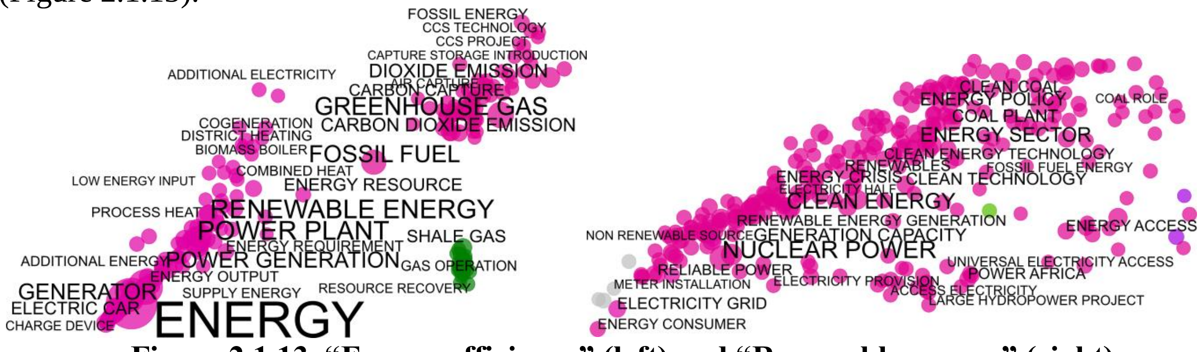


Figure 2.1.13. “Energy efficiency” (left) and “Renewable energy” (right)

In addition to achieving energy efficiency, low carbon and low emissions are important concerns. All the issues related to these topics are indicated in Figure 2.1.14 including setting targets, introducing necessary taxation systems, reducing fossil fuel use and associated emissions, and taking policy measures to mitigate climate change while increasing the wealth of the country.

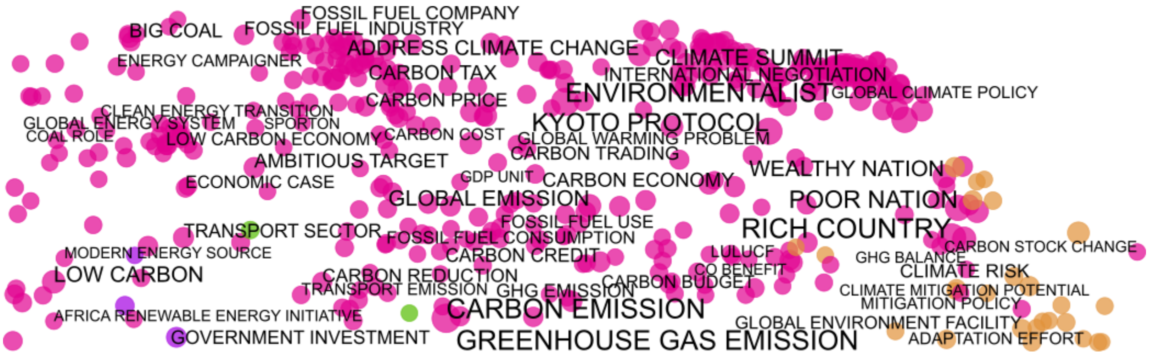


Figure 2.1.14. "Low carbon and low emissions"

Climate change mitigation and environmental conservation also need to be considered not only at the local level, but also at the regional and global levels, as these are among the key grand challenges for humanity. Synchronizing national policies, setting up carbon stock exchange systems, developing global systems for climate adaptation are among the important issues under this topic (Figure 2.1.15).

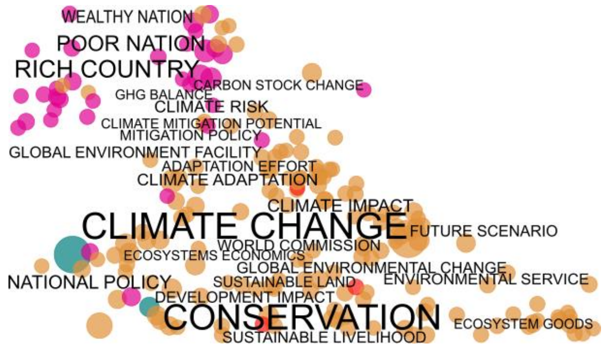


Figure 2.1.15. "Climate change"

Besides global, policy, economic and low carbon aspects, the conservation of biodiversity and more sustainable use of land also emerge as important aspects leading to a low-carbon and climate resilient economy. Issues arising under these topics are indicated in Figure 2.1.16. Regarding biodiversity conservation, a number of issues around forests emerge, including deforestation, plantation, the protection of woodland and rainforest. Habitat restoration, protection and management are important for biodiversity conservation. Indeed, the challenge of land use is closely associated to biodiversity conservation. At the intersection of both topics is the crop use with issues related to agricultural land use practices, and management of arable land, wetland, grazing land, and farmland.

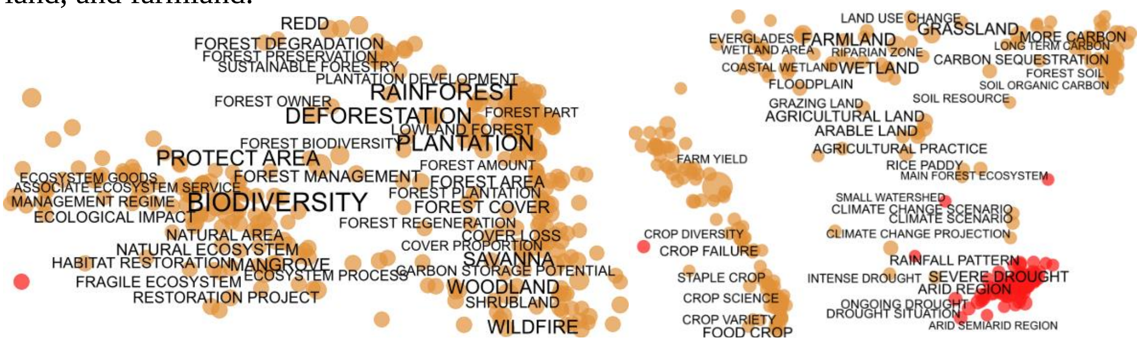


Figure 2.1.16. "Biodiversity conservation" (left) and "Land use" (right)

In order to achieve a low-carbon and climate resistant economy, there are policy actions to be taken at the continental level in Africa. African governments and institutions need to develop joint and national policies for sustainable development, greener economy and cities with better infrastructures. These need to comply with the international and global sustainable development goals (Figure 2.1.17).

Figure 2.1.17. “African environmental policy”

CE4: Smart connectivity and mobility in communities, supporting the circular economy

For the final thrust in this category regarding smart connectivity and mobility, the iFORA system detected topics clustering around greener transport systems. These include use of greener and cleaner cars as well as setting up necessary urban infrastructures to develop greener cities and livelihoods. This also includes introduction of electric cars and improving electricity access (Figure 2.1.18).

Figure 2.1.18. “Green transport”

Dynamics of circular economy thrusts

In this section, the dynamics of the circular economy thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts CE2 (Ensuring sustainable water, energy and food security) appears to be the highest on the agenda (Figure 2.1.19). However, the progress with smart connectivity and mobility are extremely low (CE4). This thrust certainly needs more research for the achievement of the goals related to circular economy.

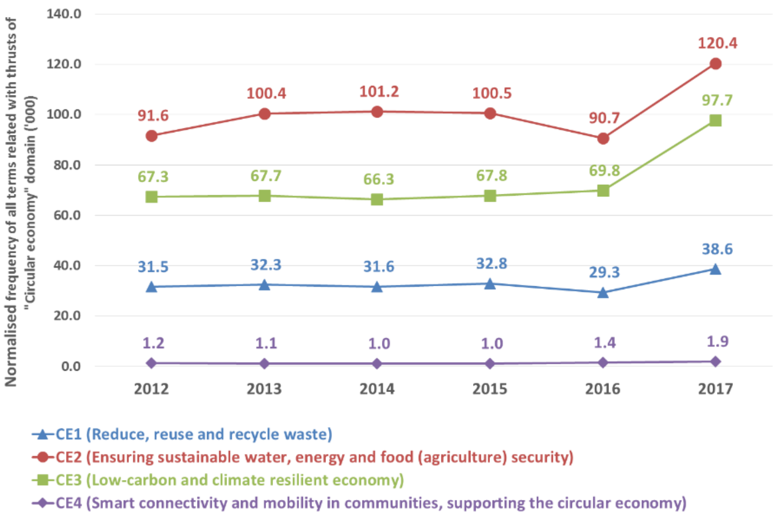


Figure 2.1.19. Normalized frequency of all terms related with thrusts of "Circular economy" domain ('000) in 2012 – 2017

Note: "Normalized frequency" for a specific thrust – is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.1.4 illustrates to what extent the Circular Economy domain thrusts address the challenges. The table indicates that most of the thrusts in the CE domain are associated to population growth (except CE4). CE4 appears to be linked with job creation though at a lesser extent compared to CE1 and CE2.

Table 2.1.4. Impacts of all thrusts of "Circular Economy" domain on challenges

Challenges	Circular Economy			
	CE1	CE2	CE3	CE4
Affordable Education	1.0	0.0	0.0	0.0
Affordable Energy	3.0	15.5	4.2	0.0
Affordable Food	1.0	3.0	2.3	0.0
Carbon Emission Reduction	0.0	10.0	15.9	0.0
Clean Water Access	1.0	2.0	1.0	0.0
Crime Prevention	1.0	2.0	1.0	0.0
Crime Reduction	0.0	0.0	0.0	0.0
Economy Growth	0.0	4.0	1.3	0.0
Employment Growth	0.0	2.8	2.4	0.0
Export Growth	0.0	9.0	3.2	0.0
High Living Standard	2.0	1.0	1.0	0.0
High Quality Health Care Service	0.0	0.0	0.0	0.0
Income Growth	1.0	9.7	4.4	0.0
Job Creation	16.5	19.1	8.5	2.0
Low Greenhouse Gas Emission	2.3	3.3	2.0	0.0
Low Mortality	0.0	0.0	1.3	0.0
Population Growth	7.0	25.6	47.9	0.0
Poverty Alleviation	9.0	2.0	4.8	0.0
Reduce Water Demand	0.0	3.0	1.0	0.0
Renewable Energy Growth	0.0	3.0	2.0	0.0
Rural Community	7.3	14.4	3.9	0.0
Secure Water Supply	1.0	1.0	1.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust CE1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.2 HIGH-TECH INDUSTRY DOMAIN

Overall description of the domain

Industry 4.0 is expected to transform products, processes and services in a revolutionary way through the application of smart and connected systems. Following these lines, the High-tech Industry domain focuses on the implementation of advanced manufacturing in South Africa by utilizing the technologies like Robotics, Artificial Intelligence (AI), Internet of Things (IoT), and Additive manufacturing among the others. Progress towards the High-tech Industry will transform old industries and will give rise to the emergence of new industries. Industrial actors including SMEs will need to equip themselves with necessary skills, infrastructure and capacity for a successful transition.

Overview of research potential of South Africa in "High-tech Industry" domain

Figure 2.2.1 shows that there is a fast growing scientific emphasis on the High-tech Industry domain in South Africa. The number of publications has been growing steadily as well as the share of South Africa in the global scientific output in this domain especially in last 3 years.

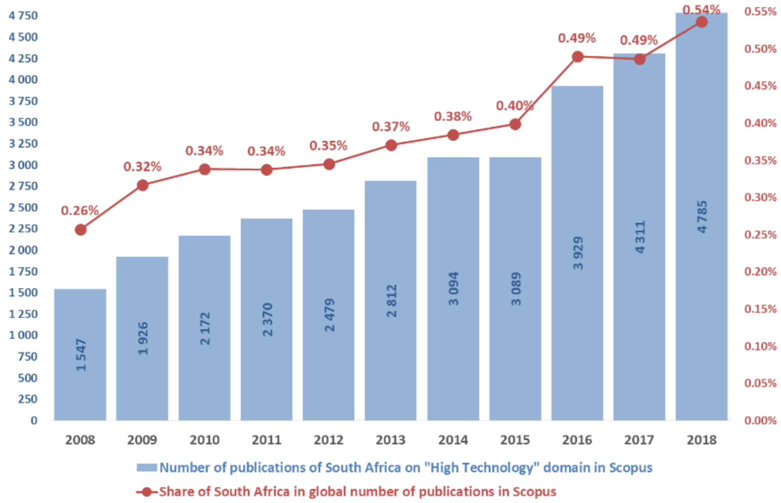


Figure 2.2.1. Dynamics of publications of South Africa in "High-tech Industry" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.2.2 shows the leading countries in the high-tech industry domain. South Africa's scientific position in High-tech Industry is poor with the 41st place in the world. Top five key collaborators of the country in this domain are the US, the UK, India, Germany and China. Other African countries rank also very low both in scientific capacity and level of collaboration (Table 2.2.1).

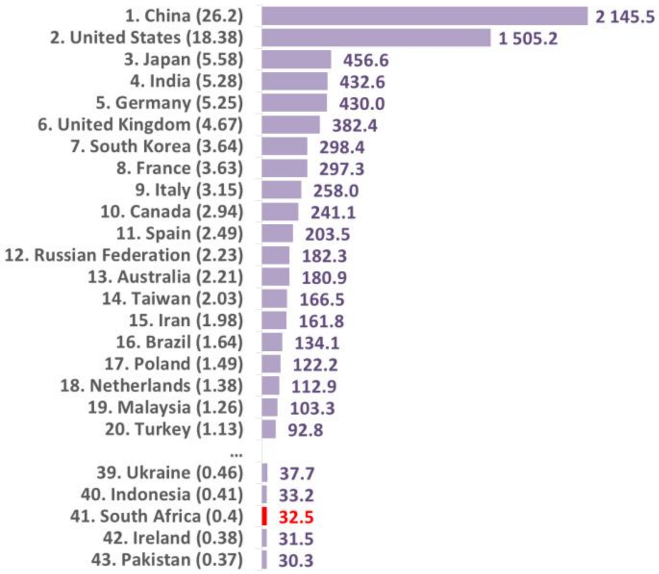


Figure 2.2.2. Leading countries by number of publications in "High-tech Industry" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 2.2.1. Key partner countries of South Africa in internationally collaborated publications in "High-tech Industry" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	2665	19.10%
United Kingdom	1982	14.20%
India	1724	12.36%
Germany	1451	10.40%
China	1330	9.53%
France	1246	8.93%
Australia	1071	7.68%
Nigeria	932	6.68%
Canada	893	6.40%
Netherlands	879	6.30%
Italy	717	5.14%
Sweden	681	4.88%
Spain	611	4.38%
Switzerland	559	4.01%
Turkey	505	3.62%
Japan	503	3.60%
Saudi Arabia	503	3.60%
Brazil	467	3.35%
Poland	435	3.12%
Iran	421	3.02%
Russian Federation	414	2.97%
Norway	403	2.89%
Denmark	399	2.86%
Belgium	395	2.83%
Austria	368	2.64%
Czech Republic	341	2.44%
Greece	314	2.25%
Portugal	301	2.16%
Chile	300	2.15%
Taiwan	296	2.12%
Hungary	290	2.08%

Romania	290	2.08%
Israel	284	2.04%
Malaysia	282	2.02%
Argentina	278	1.99%
Slovakia	277	1.99%
South Korea	262	1.88%
Serbia	234	1.68%
Armenia	226	1.62%
Morocco	226	1.62%
Finland	225	1.61%
Slovenia	224	1.61%
Colombia	220	1.58%
Hong Kong	213	1.53%
Belarus	205	1.47%
Azerbaijan	204	1.46%
Kenya	201	1.44%
Zimbabwe	199	1.43%
New Zealand	195	1.40%
Pakistan	194	1.39%
Georgia	190	1.36%
Botswana	179	1.28%
Qatar	156	1.12%
Egypt	152	1.09%
Mexico	143	1.02%
Algeria	141	1.01%
Namibia	131	0.94%
Ghana	103	0.74%
Ethiopia	100	0.72%
Thailand	100	0.72%

Table 2.2.2 shows the leading organizations in South Africa publishing in the domain of High-tech Industry with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.2.2. Leading organizations of South Africa by number of publications in "High-tech Industry" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
Universiteit van Pretoria	4036	12.41%
University of Cape Town	3925	12.07%
Universiteit Stellenbosch	3591	11.04%
University of KwaZulu-Natal	3493	10.74%
University of Johannesburg	3436	10.57%
University of Witwatersrand	3166	9.74%
The Council for Scientific and Industrial Research	2226	6.85%
Tshwane University of Technology	1756	5.40%
North-West University	1293	3.98%
University of South Africa	1192	3.67%
University of the Free State	1063	3.27%
Rhodes University	872	2.68%
Nelson Mandela Metropolitan University	717	2.21%
University of the Western Cape	702	2.16%
Cape Peninsula University of Technology	685	2.11%
Durban University of Technology	609	1.87%
Vaal University of Technology	380	1.17%
University of Fort Hare	333	1.02%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	299	0.92%

Central University of Technology, Free State	277	0.85%
South African Medical Research Council	275	0.85%
University of Zululand	249	0.77%
University of Venda for Science and Technology	222	0.68%
Meraka Institute	213	0.66%
National Research Foundation	210	0.65%
University of KwaZulu-Natal School of Chemical Engineering	203	0.62%
Mintek	201	0.62%
Sasol Technology Pty Ltd	194	0.60%
Agricultural Research Council, Pretoria	184	0.57%
University of Cape Town, Faculty of Health Sciences	160	0.49%
University of Limpopo	160	0.49%
Eskom	152	0.47%
Mangosuthu University of Technology	122	0.38%
National Health Laboratory Services	122	0.38%
NECSA	106	0.33%
Walter Sisulu University	105	0.32%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "High-tech Industry" domain

This section describes the "High Technology Industry" STI domain and its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the High-tech Industry (HT) with its clusters and interrelations to each other. A detailed analysis of Figure 2.2.3 provides an overview of CE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.2.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.2.3. "High-tech Industry (HT)" thrusts and topics

HT Thrusts		Topics emerging under each thrust
HT1: Enabling small business to adopt high tech		"IT adoption" and "High tech start-ups" (Fig. 2.2.4)
		"Skills development" (Fig. 2.2.5)
HT2: New thinking for new industries		"Artificial intelligence"; "Virtual reality" and "Gaming" (Fig. 2.2.6)
		"Cryptocurrency"; and "Biometry" (Fig. 2.2.7)
		"New technologies"; "Aerospace"; "Biotechnology" (Fig. 2.2.8)
HT3: New thinking for old industries		"Economy" and "Productivity" (Fig. 2.2.9)
		"Clean transport" and "Energy efficiency" (Fig. 2.2.10)
		"Sustainability" and "Environmental policy" (Fig. 2.2.11)
		"Climate change" and "Chemistry" (Fig. 2.2.12)

Figure 2.2.3. “High-tech industry” domain full semantic map for 2014-2018

"High-tech Industry" Thrusts

HT1: Enabling small business to adopt high tech

The iFORA system revealed two topics for the adoption of high technology in small businesses. The first one is related to mainstream IT adoption, which is necessary for all small businesses. Early adopters will gain competitive advantage to the others. Besides making existing small businesses more IT based, it is undoubtedly crucial to have high tech start-ups for a more STI based economy and society. Entrepreneurship and venture capital investment are two important drivers for setting up high tech small businesses (Figure 2.2.4).

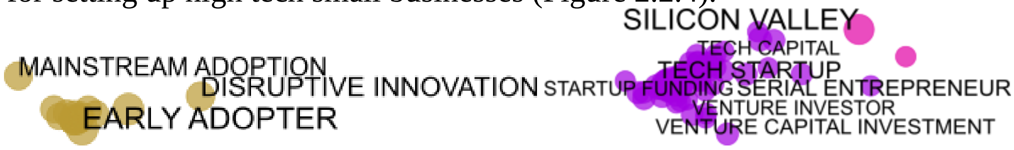


Figure 2.2.4. "IT adoption" (left) and "High tech start-ups" (right)

IT adoption by small businesses is not only about a technological issue. Skills development for high tech adoption is also an important aspect. Figure 2.2.5 demonstrates the issues related to skills development including job creation and markets, wage levels, skill requirements as well as job security and further career development. These factors combined with technical skills will have impacts on widespread IT adoption in small businesses.

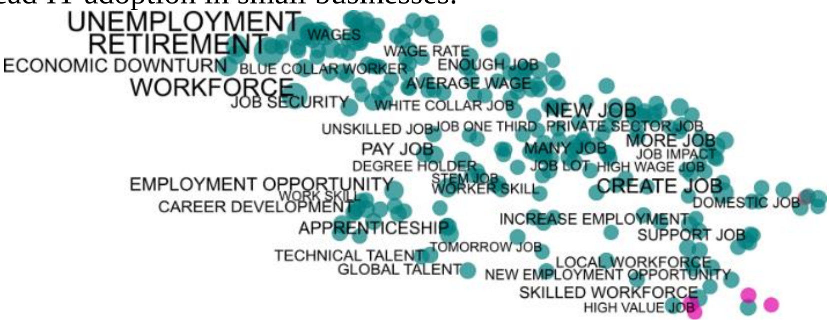


Figure 2.2.5. "Skills development"

HT2: New thinking for new industries

High-tech Industry will certainly have impacts on new and old industries. Therefore, there is a need to shift in the thinking for new industries. The iFORA system identified three technological topics, which can be the drives for a breakthrough development of new industries, including Artificial Intelligence (AI), Virtual Reality (VR) and gaming. AI appears to be important for all sorts of industries and businesses. Necessary technologies and skills need to be developed for the implementation of AI systems, such as machine learning and deep learning systems. In conjunction with AI, VR systems provide larger application areas for new industries. Particularly human-machine interaction systems will transform the way products, production processes, and provision of services. Gaming has also emerged as a new and growing market, not only for entertainment, but also for simulation and decision-making (Figure 2.2.6).

Figure 2.2.6. "Artificial intelligence" (left); "Virtual reality" (center); "Gaming" (right)

The new high technology business and industrial systems will also need to transform in terms of new economic and security systems. Cryptocurrencies are revolutionary in terms of creating more stable, secure and speedy financial transactions. Bitcoin is being experimented for several years now, and is expected to be more widespread along with all other cryptocurrencies being continuously introduced into the financial market, such as Ethereum and others. In association of cryptocurrencies, the Blockchain concept is also developing fast. Actually, cryptocurrency is only one application for Blockchain as a distributed ledger system. It has potentials to transform all sorts of industries and businesses such as energy and agriculture, which are among the key drivers of South African social and economic systems. In parallel to the emergence of digital financial systems, increasing security issues need to be addressed. These include the development of biometric systems and authentication technologies with increasing security measures (Figure 2.2.7).

Figure 2.2.7. “Cryptocurrency” (left); “Biometry” (center); “Cleantech” (right)

Among the technologies for high-tech development are additive manufacturing, 3D printing and digital design. Aerospace and biotechnology emerge as two application areas for high tech industries in South Africa. Particularly space technologies are considered to benefit from developments in this domain. Regarding biotechnology, the main areas for development are transformation into bioeconomy, development of industrial biotechnology, and biofuel industry. Without any doubt, environmental, social and ethical concerns need to be addressed regarding the implementation of biotechnologies (Figure 2.2.8).

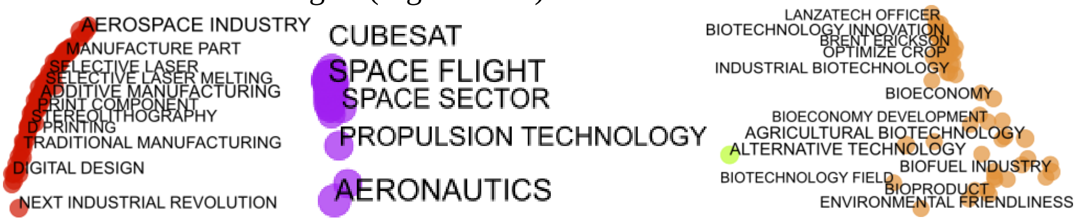


Figure 2.2.8. “New technologies” (left); “Aerospace” (center); “Biotechnology” (right)

HT3: New thinking for old industries

Besides setting up new industries with new technologies, it is also important to upgrade the old industries, which are the main backbones of development. Economic and productivity improvements are needed to make sure that old industries remain competitive. These include the development of the manufacturing industry at the national and domestic levels, supporting innovation, upgrading technologies and expanding export markets. Regarding productivity, technological and capital investments, as well as reducing cycle times and processing costs appear to be areas for action in all industries (Figure 2.2.9).

Figure 2.2.9. “Economy” (left) and “Productivity” (right)

Transport is one of the old, but rapidly developing sectors of the South African economy. Actions for the improvements of the transport systems begin with making the industry cleaner and more sustainable. Sustainable transport systems need to be developed with a balanced use of personal cars and local transport. Vehicles on the road should be clean and energy efficient. In order to increase energy efficiency, there is a need to introduce cleaner technologies for all sectors, including energy. Renewable and low carbon energy technologies should be developed, fossil fuel use should be reduced and power sector should be upgraded (Figure 2.2.10).

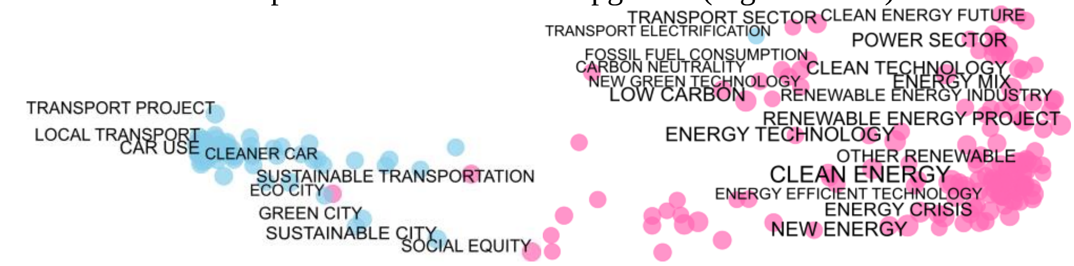


Figure 2.2.10. "Clean transport" (left) and "Energy efficiency" (right)

In line with energy efficiency, overall improvements in sustainability are needed. Green innovation and initiatives should be in place with reduced ecological footprint and decarbonization. Besides environmental sustainability, social sustainability is also important for a more sustainable future. This requires political will, leadership and stewardship with environmental policies in place (Figure 2.2.11).

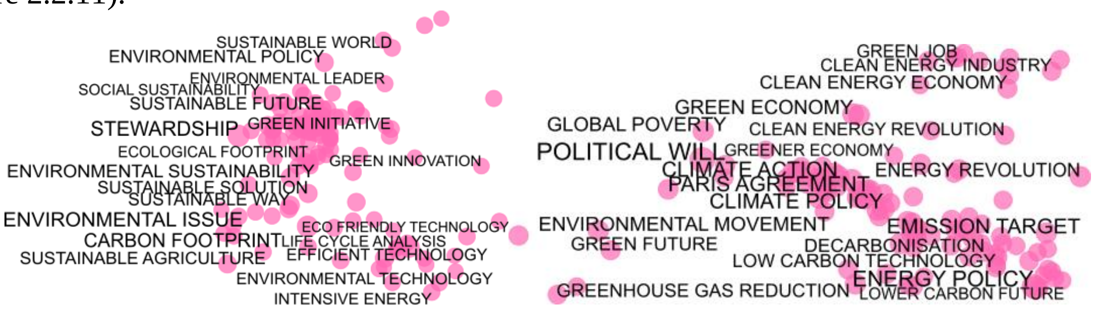


Figure 2.2.11. "Sustainability" (left) and "Environmental policy" (right)

Old industries like agriculture and chemistry should also be considered with new thinking. Climate change effects like flooding should be observed with mitigation policies and actions, such as through more efficient water management and agricultural production systems. Similarly, the chemistry industry needs to be development to make it greener and more environmentally friendly with advanced processes and production systems (Figure 10).

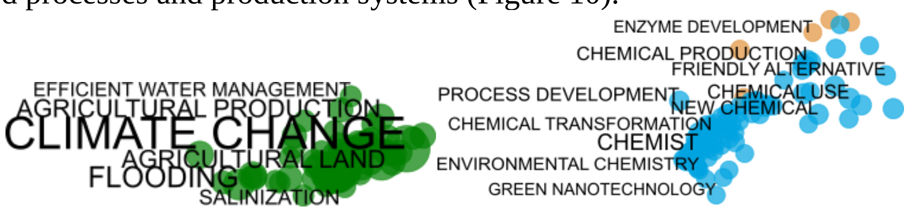


Figure 2.2.12. "Climate change" (left) and "Chemistry" (right) fragments

Dynamics of "High-tech industry" domain thrusts

In this section, the dynamics of "high-tech industry" thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts HT3 (New thinking for new industries) appears to the highest on the agenda with an increasing growth rate (Figure 2.2.13). This is certainly promising as the research trends support the agenda of the 4th industrial revolution. However, research on small businesses to adopt high-tech is relatively low without a significant progress across years.

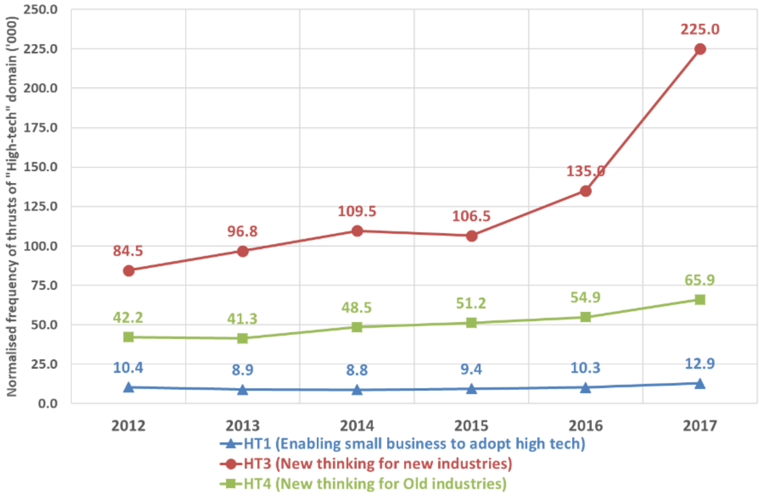


Figure 2.2.13. Normalised frequency of all terms related with thrusts of "High-tech industry" domain ('000) in 2012 – 2017

Notes. 1. "Normalized frequency" for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year. 2. The HT2 thrust has been moved to "Education" domain and became ED1 "Skills for the 4th Industrial Revolution" thrust.

Furthermore, Table 2.2.4 illustrates to what extent the "High-tech industry" domain thrusts address the challenges. HT4 is extremely linked to job creation. HT3 has also a strong linkage with the same challenge along with population growth. HT1 is the only thrust, which appears to be linked with income growth.

Table 2.2.4. Impacts of all thrusts of "High-tech industry" domain on challenges

Challenges	High-tech		
	HT1	HT3	HT4
Affordable Education	0.0	5.0	1.5
Affordable Energy	0.0	0.0	9.0
Affordable Food	0.0	0.0	0.0
Carbon Emission Reduction	0.0	1.5	2.0
Clean Water Access	0.0	0.0	1.0
Crime Prevention	0.0	1.0	1.0
Crime Reduction	0.0	2.0	0.0
Economy Growth	0.0	1.0	1.0
Employment Growth	0.0	3.0	23.0
Export Growth	0.0	1.0	3.0
High Living Standard	0.0	5.5	4.0
High Quality Health Care Service	0.0	0.0	0.0
Income Growth	1.0	1.3	6.0
Job Creation	0.0	36.6	133.1
Low Greenhouse Gas Emission	0.0	0.0	2.0
Low Mortality	0.0	0.0	0.0
Population Growth	0.0	53.8	24.0
Poverty Alleviation	0.0	2.0	11.8
Reduce Water Demand	0.0	0.0	1.0
Renewable Energy Growth	0.0	1.0	0.0
Rural Community	0.0	13.0	26.6
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0
Universal Broadband Access	0.0	1.0	1.5

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust HT1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.3. NUTRITION SECURITY FOR A HEALTHY POPULATION (NUTRITION) DOMAIN

Overall description of the domain

Good nutrition is essential for a health population. There are currently serious issues around malnutrition and stunting in South Africa. Particularly women and children are in a disadvantaged position. There are economic (low income, unemployment etc.) and environmental (climate change) drivers of the health and nutrition related problems. Technologies like precision farming are considered to create opportunities for advancing farming in South Africa and making efficient use of arable land by reducing pressures due to climate change, waste and pollution. Hence, the nutrition security domain focuses on zero impact agriculture as well as the application of advanced technologies like biotechnologies, precision agriculture as well as big data.

Overview of research potential of South Africa in "Nutrition" domain

Figure 2.3.1 shows that there is a growing scientific emphasis on the Nutrition security domain in South Africa. The number of publications has growing gradually as well as the share of South Africa in the global scientific output in this domain.

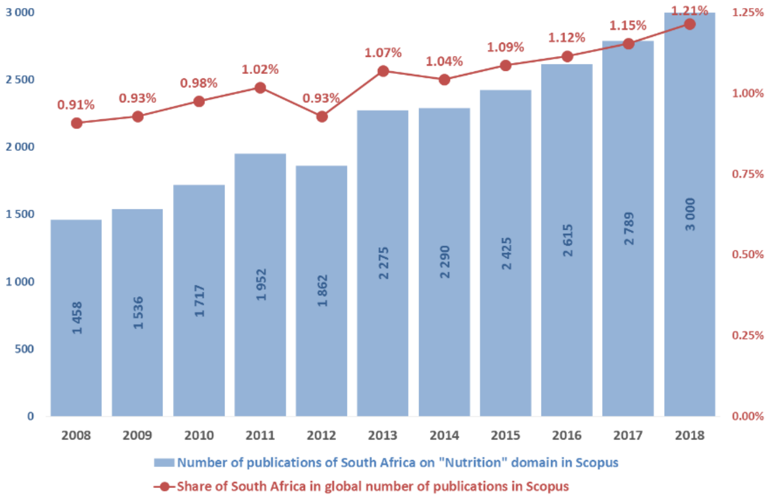


Figure 2.3.1. Dynamics of publications of South Africa in "Nutrition" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.3.2 shows the leading countries in the Nutrition security domain. As the most advanced country in Africa, South Africa has the 25th position in the world in this domain.

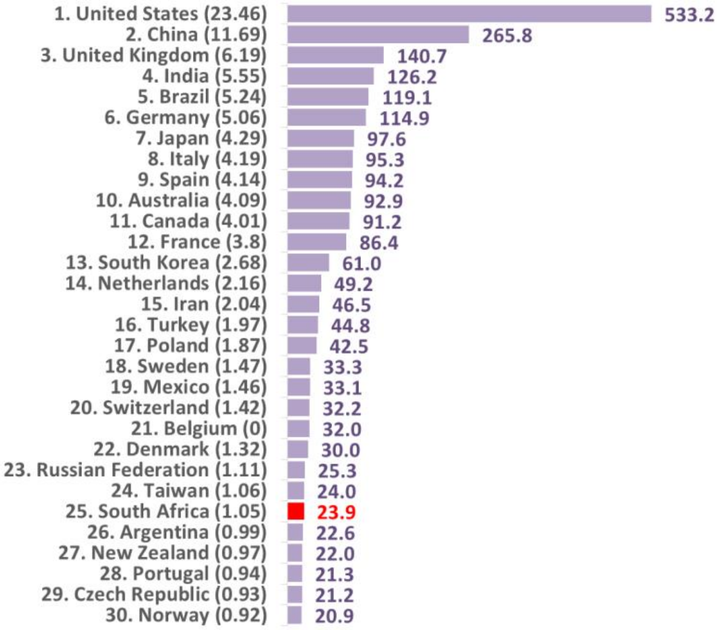


Figure 2.3.2. Leading countries by number of publications ('000) in "Nutrition" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa in the Nutrition security domain are the United States, the United Kingdom, Australia, Germany and France. African countries like Nigeria and Zimbabwe are among the top collaborators in the Africa continent (Table 2.3.1).

Table 2.3.1. Key partner countries of South Africa in internationally collaborated publications in "Nutrition" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	3357	27.77%
United Kingdom	2244	18.56%
Australia	1457	12.05%
Germany	1106	9.15%
France	1060	8.77%
Netherlands	938	7.76%
Canada	829	6.86%
Nigeria	674	5.58%
Belgium	644	5.33%
Switzerland	594	4.91%
India	563	4.66%
Kenya	563	4.66%
Spain	556	4.60%
Italy	533	4.41%
China	532	4.40%
Sweden	501	4.14%
Brazil	457	3.78%
Zimbabwe	416	3.44%
Norway	383	3.17%
Portugal	373	3.09%
Denmark	356	2.95%
New Zealand	305	2.52%
Cameroon	293	2.42%
Japan	293	2.42%
Russian Federation	268	2.22%

Ethiopia	264	2.18%
Tanzania	262	2.17%
Czech Republic	239	1.98%
Argentina	237	1.96%
Finland	236	1.95%
Ghana	226	1.87%
Uganda	211	1.75%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.3.2 shows the leading organizations in South Africa publishing in the domain of Nutrition security with the total number of publications they produced in the last 10 years. Top four universities publish more than half of research in this domain.

Table 2.3.2. Leading organizations of South Africa by number of publications in "Nutrition" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
Universiteit van Pretoria	3969	16.59%
Universiteit Stellenbosch	3422	14.31%
University of KwaZulu-Natal	3167	13.24%
University of Cape Town	2968	12.41%
University of Witwatersrand	1679	7.02%
North-West University	1262	5.28%
Rhodes University	1202	5.03%
University of the Free State	1115	4.66%
Agricultural Research Council, Pretoria	1108	4.63%
South African Medical Research Council	1038	4.34%
University of Johannesburg	816	3.41%
South African National Biodiversity Institute	693	2.90%
University of the Western Cape	677	2.83%
University of Fort Hare	605	2.53%
Nelson Mandela Metropolitan University	570	2.38%
University of Limpopo	516	2.16%
Tshwane University of Technology	503	2.10%
The Council for Scientific and Industrial Research	396	1.66%
South African Institute for Aquatic Biodiversity	390	1.63%
Cape Peninsula University of Technology	351	1.47%
University of South Africa	347	1.45%
University of KwaZulu-Natal, Pietermaritzburg Campus	330	1.38%
Plant Protection Research Institute, Pretoria	328	1.37%
ARC Infruitec-Nietvoorbij	321	1.34%
University of Venda for Science and Technology	317	1.33%
National Health Laboratory Services	262	1.10%
Onderstepoort Veterinary Institute	243	1.02%
Groote Schuur Hospital	232	0.97%
South African Sugarcane Research Institute	220	0.92%
Compton Herbarium	210	0.88%
Human Sciences Research Council of South Africa	195	0.82%
Citrus Research International Pty Ltd, South Africa	192	0.80%
University of Zululand	174	0.73%
Marine and Coastal Management	174	0.73%
University of Cape Town, Faculty of Health Sciences	169	0.71%
National Institute for Communicable Diseases	163	0.68%
Durban University of Technology	146	0.61%
Walter Sisulu University	145	0.61%
The Nelson R. Mandela Medical School	141	0.59%
Sefako Makgatho Health Sciences University SMU	131	0.55%
South African Environmental Observation Network	121	0.51%

Tygerberg Hospital	102	0.43%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Nutrition" domain

This section describes the "Nutrition Security for a Healthy Population" STI domain and its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the Nutrition Security for a Healthy Population (NU) with its clusters and interrelations to each other. A detailed analysis of Figure 2.3.3 provides an overview of NU thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.3.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.3.3. "Nutrition Security for a Healthy Population" thrusts and topics

Nutrition Security Thrusts	Topics emerging under each thrust
NU1: Zero Impact Agriculture	"Waste problems" and "Agricultural water management" (Fig. 2.3.4)
	"Organic and ecological farming" and "Food labeling" (Fig. 2.3.5)
	"Entrepreneurship" and "Small agriculture" (Fig. 2.3.6)
	"Agricultural policy" and "Sustainability" (Fig. 2.3.7)
NU2: Use and acceptance of modern biotechnology	"Crop GMO" and "Plant genomics" (Fig. 2.3.8)
	"Plant gene engineering" and "Pest resistant crops" (Fig. 2.3.9)
	"Crop yield management" and "Crop science" (Fig. 2.3.10)
NU3: Personalized information for healthy nutrition for all	"Malnutrition" and "Nutrition diseases" (Fig. 2.3.11)
	"Eating behavior" and "Dieting problems" (Fig. 2.3.12)
	"Sugar food" and "Junk food" (Fig. 2.3.13)
	"Healthy eating behavior" and "Health food policy" (Fig. 2.3.14)
NU4: Precision & big data in agri-businesses	"Precision agriculture" (Fig. 2.3.15)

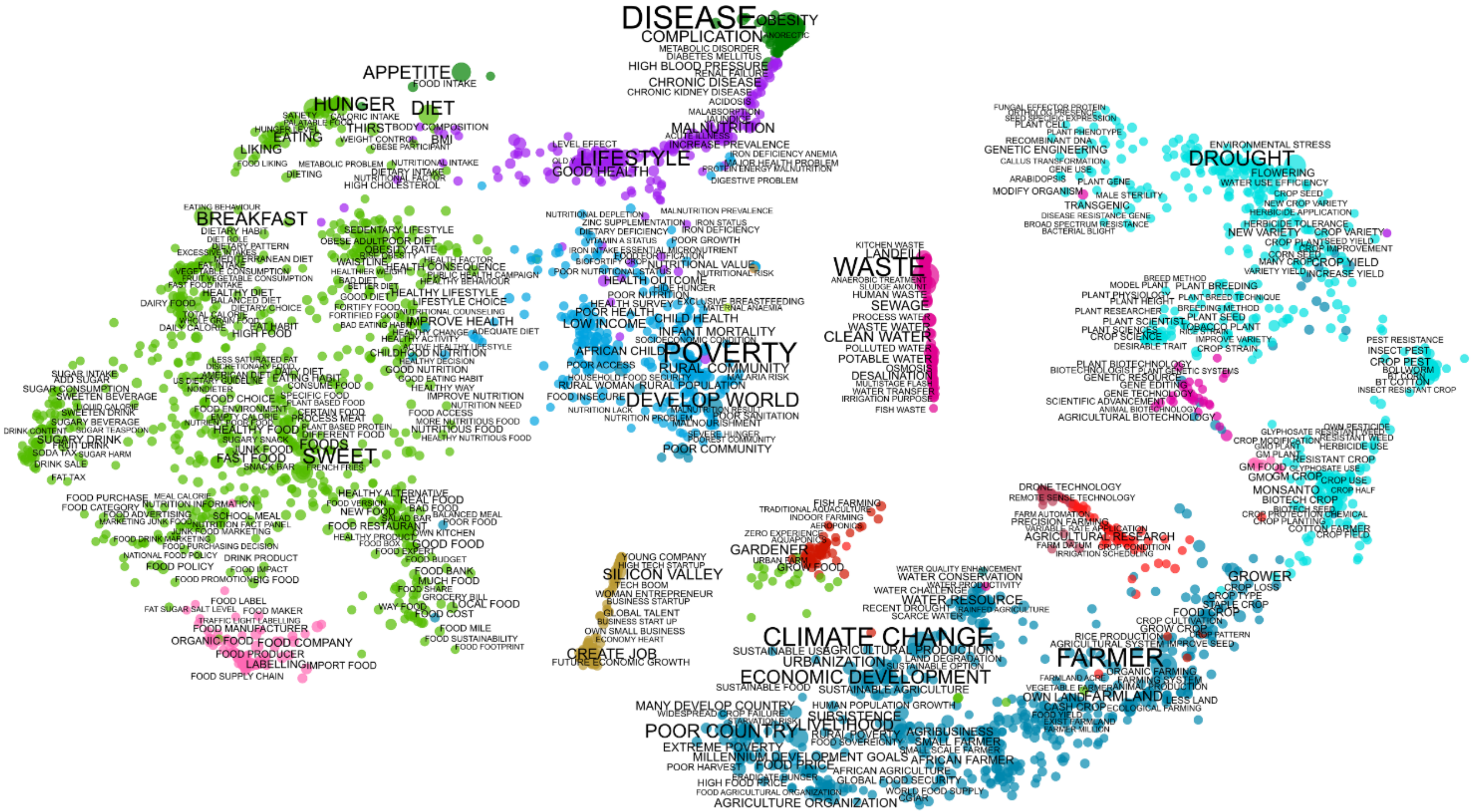


Figure 2.3.3. “Nutrition Security for a Healthy Population” domain full semantic map for 2014-2018

“Nutrition Security for a Healthy Population” Thrusts
NU1: Zero Impact Agriculture

One of key steps for achieving zero impact agriculture is reducing waste. The iFORA analysis revealed that the biggest problem related to waste in Agriculture concerns water related issues. Besides polluted and wastewater, sewage and treatment, other types of waste such as food and kitchen waste and fish waste emerge as related issues. In order to reduce water waste and make use of limited water resources efficiently, managing agricultural water emerges as an important topic. There is a need to increase water productivity and develop water quality (Figure 2.3.4).

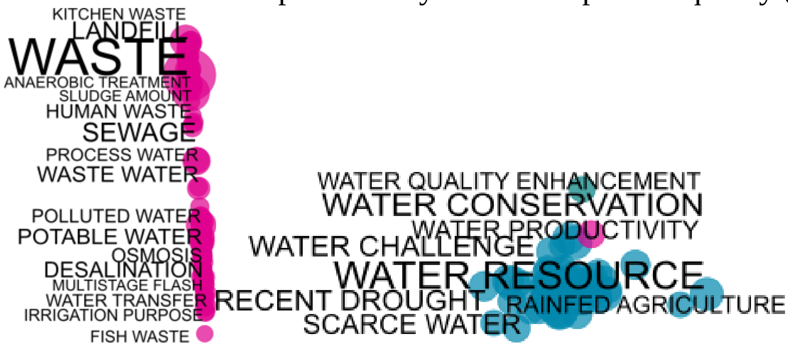


Figure 2.3.4. “Waste problems” (left) and “Agricultural water management” (right)

Zero impact agriculture and providing healthy nutrition population require organic and ecological farming and food labeling in order to protect consumer health in terms of food safety and nutrition. Organic and ecological farming covers a range of issues from the quality and quantity of the farmland and crops to cultivation and eventual food yield. Food labeling is an important and direct way of communicating information about food and its ingredients to the consumer. Food labels include any written or pictorial information attached to a food package or a container. Labels include information on ingredients, quality and nutritional value of the food. Especially fat and sugar information and salt level of food are frequently looked at besides the other nutritional values. Food manufacturers/producers play an important role in indicating food labels accurately and in a visible and accessible way to consumers (Figure 2.3.5).

Figure 2.3.5. “Organic and ecological farming” (left) and “Food labeling” (right)

Entrepreneurship and small agriculture emerge as two other issues under zero impact agriculture thrust. Entrepreneurship in this regard is concerned with start-ups and small businesses, which are crucial in employment and future economic growth in the country. Small agriculture also provides food for a large amount of population, especially for the ones, which have no economic means of accessing food markets and supermarkets. Besides these, small farming and growing own food is becoming popular in urban and peri-urban areas through urban farming and indoor farming, where food is produced nearby where it is consumed (Figure 2.3.6).

Figure 2.3.6. “Entrepreneurship” (left) and “Small agriculture” (right)

Zero impact agriculture and moving towards a society with healthy nutrition also require strong agricultural policies and measures for sustainability. There are a number of issues on the agenda of the agricultural policy, ranging from macro to micro level issues. These include policies for meeting sustainable/millennium development goals, world food supply and food security at the global level. Developing the state of the African farmers, dealing with extreme poverty and high food prices are also on the agenda. Besides providing food for population, policy issues should also address the sustainability concerns, which cover achieving economic development and urbanization while mitigating the impacts of climate change, and making agriculture and food more sustainable (Figure 2.3.7).

Figure 2.3.7. “Agricultural policy” (left) and “Sustainability” (right)

NU2: Use and acceptance of modern biotechnology

Evolving and emerging technologies provide plenty of opportunities for tackling grand challenges. Similarly biotechnologies are increasingly used for the agriculture and food sector. Genetically modified crops have been considered as a way to produce resistant and nutritious crops through genetic modification. Although this appears beneficial, in principle, a number of concerns have been raised about the health and environmental impacts of GMOs. Issues around the GMO crops are related to crop modification, pesticide use and resistant weeds among the others. Regarding plant genomics, the key issues are clustered around gene technology, plant and animal biotechnology as well as gene editing, which are the scientific fields with rapid technological development in the world and in South Africa (Figure 2.3.8).

Figure 2.3.8. “Crop GMO” (left) and “Plant genomics” (right)

Among the technologies used for plant gene engineering in South Africa the iFORA analysis revealed several application areas in plant cells, phenotypes, callus transformation, transgenic and bacterial blights. Among the key aims of plant gene engineering are developing pest resistant crops against insects and other pests (Figure 2.3.9).

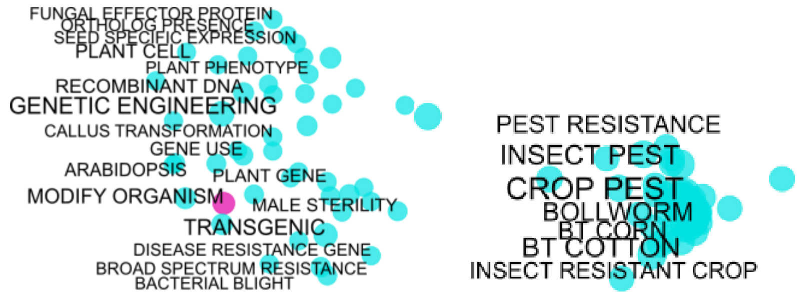


Figure 2.3.9. “Plant gene engineering” (left) and “Pest resistant crops” (right)

Modern technologies in agriculture are also used to improve crop yield to increase crop variety, improve herbicide tolerance as well as providing water use efficiency with lower environmental stress. Crop science related to breeding also appears as an important area of research in South Africa (Figure 2.3.10).

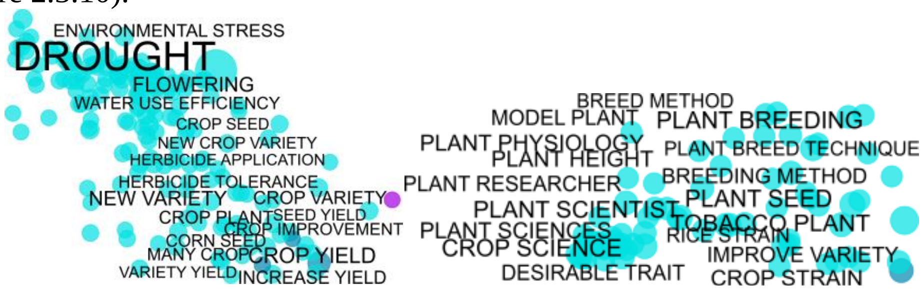


Figure 2.3.10. “Crop yield management” (left) and “Crop science” (right)

NU3: Personalized information for healthy nutrition for all

Healthy nutrition for all is a challenge for multiple aspects including, agriculture, food, health, economic condition, environment, lifestyle as well as urban-rural issues. Malnutrition is a key problem in many developing countries in the world as well as in South Africa. Among the main drivers for malnutrition are low income and poverty, poor access to food, food insecurity and resultant poor health, infant mortality and other dietary deficiency related to the lack of iron, zinc and other nutrients. These give rise to a number of diseases and major health problems such as high blood pressure, metabolic disorders, diabetes, obesity, anemia, kidney disorders among the others, which are commonly seen in Africa (Figure 2.3.11).

Figure 2.3.11. “Malnutrition” (left) and “Nutrition diseases” (right)

Eating behaviors are closely related to dietary problems. In today’s world, large amount of populations in developed, developing or under-developed countries suffer from unhealthy diets. These are related to issues regarding daily calorie intake, balanced diet, vegetable and fruit consumption, and consumption of whole grain food. Failure in providing healthy diet results with hunger, thirst, high cholesterol, obesity and other metabolic dieting problems (Figure 2.3.12).

Figure 2.3.12. "Eating behavior" (left) and "Dieting problems" (right)

In particular, sugar and junk food consumption emerge as two important problems in dietary problems. Sugar intake in the world has increased dramatically with sugary/sweetened drinks and food. Especially the use of unhealthy sugars in diet causes serious health problems. Taxes on fat soda are proposed in order to reduce the unhealthy consumption, which gives rise to higher levels of obesity. Junk food is one of the main causes of dieting problems due to the high level of sugar they contain. Changing lifestyles and food choices make people to consume more unhealthy food like processed meat, French fries and sugary snacks (Figure 2.3.13).

Figure 2.3.13. "Sugar food" (left) and "Junk food" (right)

Healthy eating behavior includes not only consuming healthy products and maintaining balanced meal. Ensuring food sustainability and reducing food print should also be among the main concerns. Proper health policies should be formulated for improving health, encouraging a healthy lifestyle, provide access to nutritious food by the larger groups of society while reducing bad diet and obesity (Figure 2.3.14).

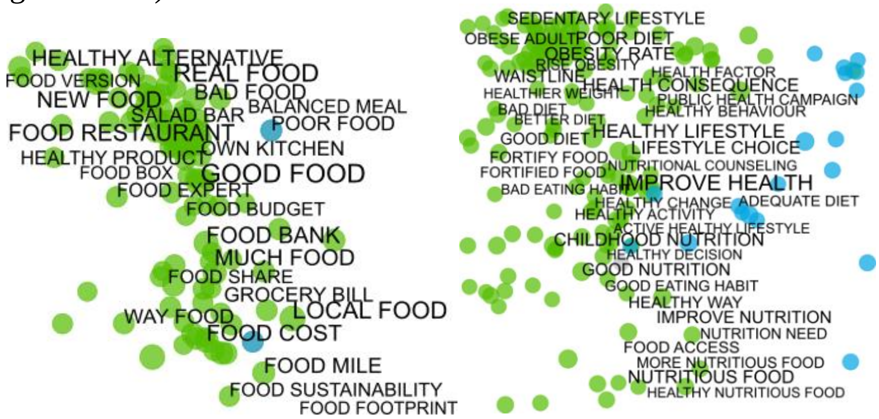


Figure 2.3.14. "Healthy eating behaviour" (left) and "Health food policy" (right)

NU4: Precision & big data in agri-businesses

Besides bio- and crop technologies, other technologies are emerging to improve farming practice, and in turn producing more nutritious and sustainable food. Among these are precision farming, farm automation technologies and remote sensing technologies. Development and implementation of these technologies require close collaboration between scientists, industry and policy makers to make sure that these technologies are available and accessible by the farmers in daily agricultural practices (Figure 2.3.15).

Figure 2.3.15. "Precision agriculture"

Dynamics of "Nutrition" domain thrusts

In this section, the dynamics of the "Nutrition" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts NU3 (Personalized information for healthy nutrition for all) appears to be the highest on the agenda (Figure 2.3.16).

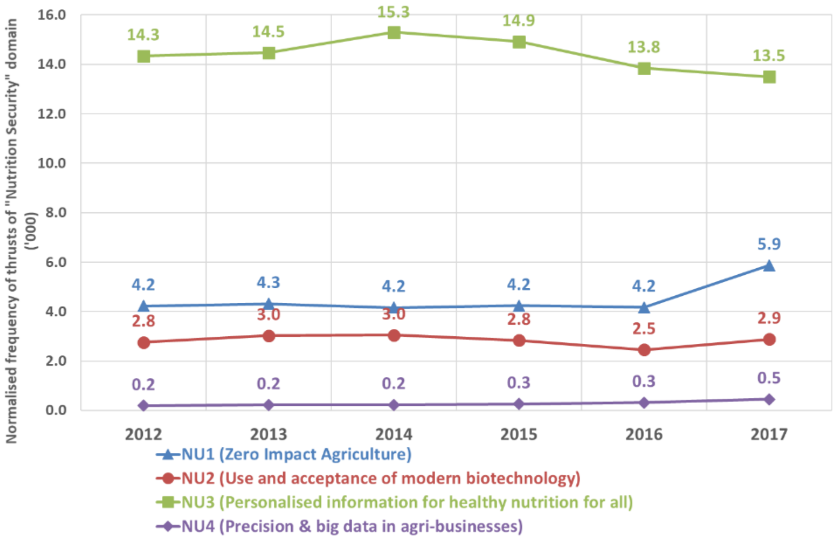


Figure 2.3.16. Normalised frequency of all terms related with thrusts of "Nutrition" domain ('000) in 2012 – 2017

Note: "Normalised frequency …" for a specific thrust – is a total normalised number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Table 2.3.4 illustrates to what extent the “Nutrition security” domain thrusts address the challenges. The use and acceptance of modern biotechnology (NU2) is strongly linked to affordable food. Personalized information for healthy nutrition for all (NU3) is instrumental in addressing low mortality and population growth. Finally zero impact agriculture (NU1) shows a considerable association to rural communities.

Table 2.3.4. Impacts of all thrusts of “Nutrition” domain on challenges

Challenges	Nutrition Security			
	NU1	NU2	NU3	NU4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	5.5	0.0	4.3	0.0
Affordable Food	2.5	103.0	20.7	0.0
Carbon Emission Reduction	0.0	0.0	1.0	0.0
Clean Water Access	2.5	1.0	1.0	0.0
Crime Prevention	4.0	0.0	5.0	0.0
Crime Reduction	0.0	0.0	1.0	0.0
Economy Growth	0.0	0.0	0.0	0.0
Employment Growth	0.0	0.0	4.5	0.0
Export Growth	0.0	2.0	3.0	0.0
High Living Standard	3.0	3.0	2.0	0.0
High Quality Health Care Service	0.0	0.0	2.0	0.0
Income Growth	14.5	5.0	12.0	2.0
Job Creation	11.3	4.7	9.0	1.0
Low Greenhouse Gas Emission	2.0	2.0	2.7	0.0
Low Mortality	1.0	10.0	49.3	0.0
Population Growth	9.7	18.0	47.0	0.0
Poverty Alleviation	10.0	8.0	13.0	0.0
Reduce Water Demand	8.0	8.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	1.0	0.0
Rural Community	28.0	9.8	21.3	5.0
Secure Water Supply	9.0	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust NU1) and a specific challenge (e.g. “Low Mortality”) in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.4. INFORMATION AND COMMUNICATION TECHNOLOGIES: OPPORTUNITIES, THREATS AND IMPACTS (ICT) DOMAIN

Overall description of the domain

Information and Communication Technologies (ICTs) are one of the key enablers of development in all domains from agriculture to health, industry to governance and service delivery. There are a number of technologies under the umbrella of ICTs. The Internet of Things (IoT) promises a hyper-connected and ultra-digitally responsive society that supports human, societal and environmental developments. Artificial intelligence offers unique opportunities to improve human lives and to address major societal challenges. Blockchain technology is expected to disrupt several markets by ensuring trustworthy transactions without the necessity of a third party. All these technologies bring opportunities and threats for socio-economic systems. Therefore, their development needs to be regulated by addressing the concerns regarding security, privacy, equity and integrity.

Overview of research potential of South Africa in "ICT" domain

Figure 2.4.1 shows that there is a growing scientific emphasis on the ICT domain in South Africa. However, the number of publications and the share of South Africa in the global scientific output in this domain remain still very low. Clearly more research in this domain is critical for the achievement of the 2030 goals and targets, as the ICTs are key drivers of development almost in all of the domains covered by the National Foresight 2030 study.

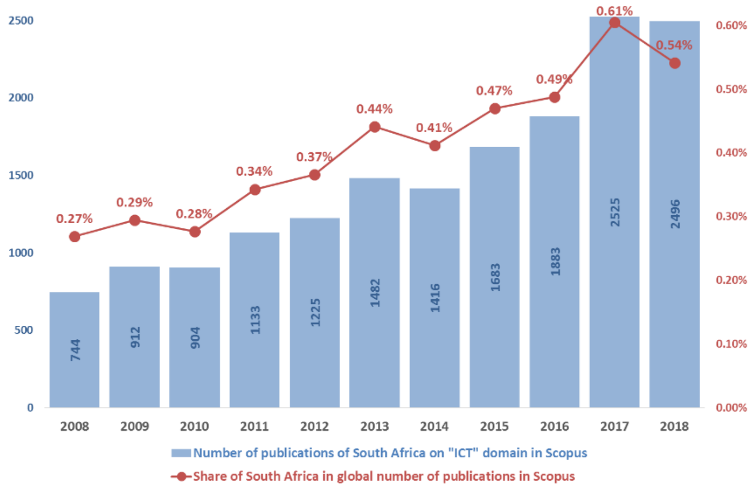


Figure 2.4.1. Dynamics of publications of South Africa in "ICT" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.4.2 shows the leading countries in the ICT domain. South Africa's position in ICTs is extremely low (45th place in the world). Top collaborators in this domain are similar to other domains (Table 2.3.1).

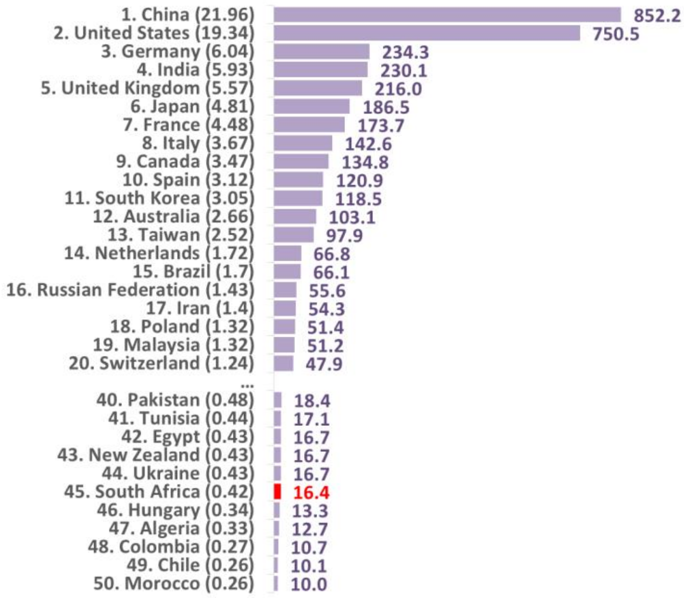


Figure 2.4.2. Leading countries by number of publications on "ICT" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Table 2.4.1. Key partner countries of South Africa in internationally collaborated publications in "ICT" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with SAR	Share of a country in all ICPs of South Africa
United States	1181	20.82%
United Kingdom	902	15.90%
Germany	627	11.05%
France	481	8.48%
China	433	7.63%
Australia	430	7.58%
Canada	392	6.91%
Netherlands	368	6.49%
India	341	6.01%
Italy	284	5.01%
Nigeria	273	4.81%
Sweden	206	3.63%
Belgium	155	2.73%
Switzerland	155	2.73%
Spain	152	2.68%
Finland	134	2.36%
Namibia	132	2.33%
Austria	124	2.19%
Brazil	115	2.03%
Zimbabwe	110	1.94%
Denmark	99	1.75%
Japan	99	1.75%
Norway	97	1.71%
Kenya	94	1.66%
Botswana	93	1.64%
Turkey	89	1.57%
New Zealand	87	1.53%
Saudi Arabia	84	1.48%
Poland	76	1.34%
South Korea	71	1.25%

Singapore	64	1.13%
Ghana	63	1.11%
Ireland	63	1.11%
Hong Kong	61	1.08%
Russian Federation	60	1.06%
Portugal	59	1.04%
Mexico	55	0.97%
Iran	53	0.93%
Malaysia	53	0.93%
Greece	51	0.90%
Argentina	50	0.88%

Table 2.4.2 shows the leading organizations in South Africa publishing in the domain of ICT with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output. The number of publications is considerably low considering the importance of the ICT domain.

Table 2.4.2. Leading organizations of South Africa by number of publications in "ICT" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
Universiteit van Pretoria	2349	14.32%
University of Cape Town	2224	13.56%
University of Johannesburg	1863	11.36%
University of KwaZulu-Natal	1567	9.55%
The Council for Scientific and Industrial Research	1551	9.46%
Universiteit Stellenbosch	1370	8.35%
University of Witwatersrand	1179	7.19%
University of South Africa	1053	6.42%
Tshwane University of Technology	914	5.57%
North-West University	627	3.82%
Meraka Institute	558	3.40%
Nelson Mandela Metropolitan University	456	2.78%
Rhodes University	410	2.50%
University of the Western Cape	337	2.05%
Cape Peninsula University of Technology	336	2.05%
Durban University of Technology	252	1.54%
University of the Free State	224	1.37%
University of Fort Hare	169	1.03%
Central University of Technology, Free State	160	0.98%
University of Zululand	154	0.94%
Vaal University of Technology	150	0.91%
University of Limpopo	106	0.65%
South African Medical Research Council	102	0.62%
South African Astronomical Observatory	93	0.57%
University of Venda for Science and Technology	79	0.48%
Eskom	57	0.35%
Walter Sisulu University	51	0.31%
African Institute for Mathematical Sciences	50	0.30%
Square Kilometre Array, South Africa	49	0.30%
Mangosuthu University of Technology	45	0.27%
Nelson Mandela University	37	0.23%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	33	0.20%
South African National Space Agency	31	0.19%
Groote Schuur Hospital	27	0.16%
University of Cape Town, Faculty of Health Sciences	26	0.16%
Agricultural Research Council, Pretoria	25	0.15%

Stellenbosch Institute for Advanced Study	25	0.15%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of the "ICT" domain

This section describes the "The Opportunities, Threats and Impact of ICTs (including Smart Systems, on Society)" STI domain its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The second section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.3.3 shows the entire domain of the Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society (IT) with its clusters and interrelations to each other. A detailed analysis of Figure 2.4.3 provides an overview of IT thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.4.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.4.3. "The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society" thrusts and topics

IT Thrusts	Topics emerging under each thrust
IT1: Checks and balances for a digital future	"Identity security" and "Cybersecurity" (Fig. 2.4.4)
	"Privacy issues" (Fig. 2.4.5)
	"Ethical issues of ICT" and "Media, news and trust" (Fig. 2.4.6)
IT2: Internet Access & the Network & Information Infrastructure	"Broadband access promotion" and "Cloud based systems" (Fig. 2.4.7)
IT3: Big Data, Data Analytics and Decision Support	"Sensor networks and wireless infrastructure" and "Real time data" (Fig. 2.4.8)
	"Big data analytics" and "Decision support" (Fig. 2.4.9)
	"IT in education" (Fig. 2.4.10)
IT4: Smart and sustainable Municipal Service delivery	"Smart systems (city, energy, transport)" (Fig. 2.4.11)
	"Energy, electricity and utilities" (Fig. 2.4.12)
	"Smart governance" and "Cryptocurrency" (Fig. 2.4.13)

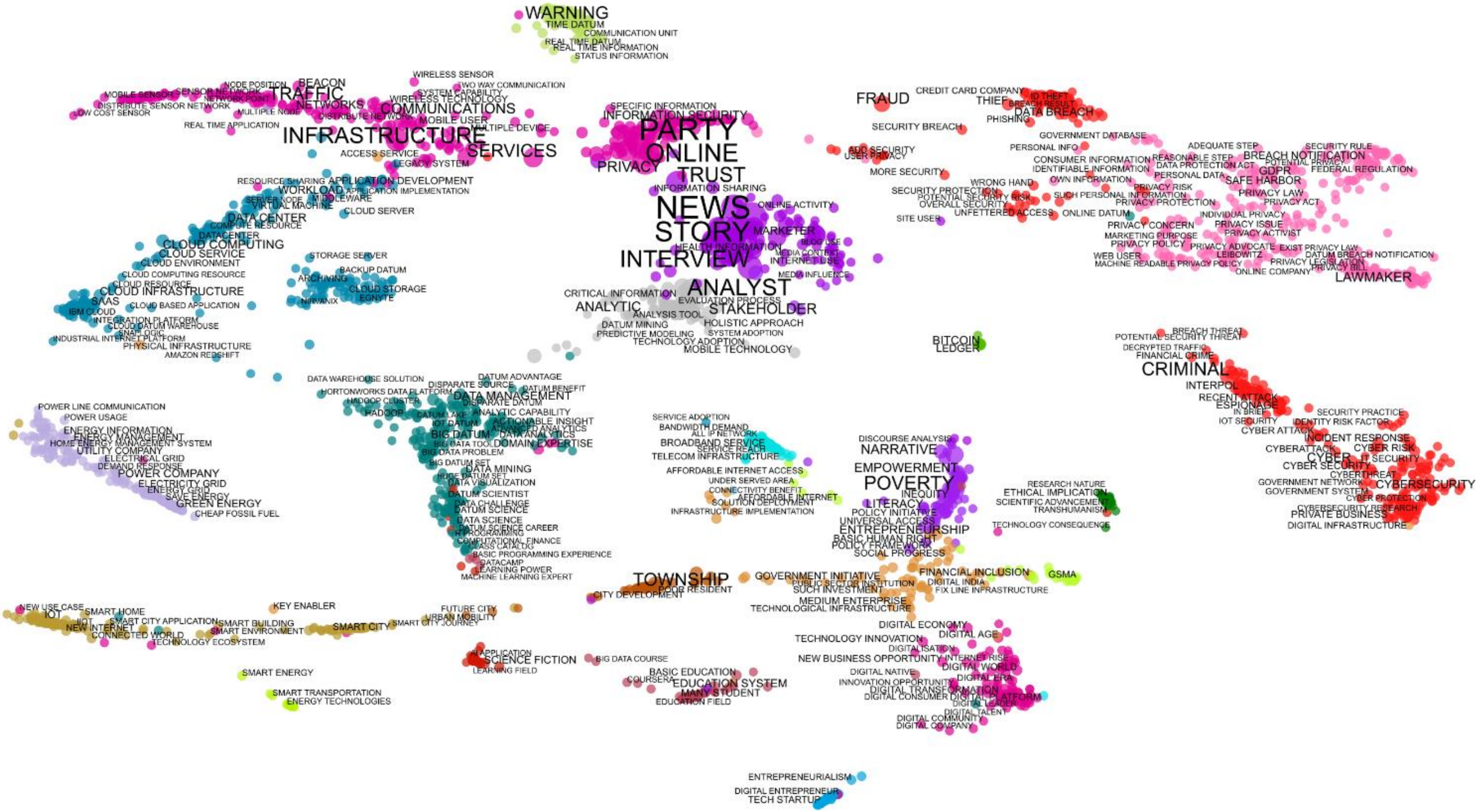


Figure 2.4.3. "The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society" domain full semantic map for 2014-2018

"The Opportunities, Threats and Impact of ICTs, including Smart Systems, on Society" Thrusts

IT1: Checks and balances for a digital future

The first thrust of the IT domain is concerned with the societal impacts of the rapidly developing Information and Communication Technologies (ICTs). Many intended and unintended consequences are emerging with significant impacts. The analysis with the iFORA system revealed five important points, which are concerned with security and privacy as well as ethical and trust issues. These are presented respectively from Figures 2.4.4. to 2.4.6. Identity theft and fraud are emerging as important concerns in parallel to the more widespread use of the ICTs. Personal information is collected through online systems by a wide variety of parties including the governmental agencies, internet operators, applications, online marketing and retail sites among the others. Therefore, strict protection and regulations are needed to make sure that this sensitive information does not go into wrong hands, which may result with ID theft. Today the worldwide information security spending has almost reached 124 billion USD[4]. This large amount is an indicator of how crucial the issue is. Setting up a safe and secure digital infrastructure is the first step for cyber protection. Particularly governmental systems and networks may be vulnerable. However, private businesses are also under risk of cyber-attacks. There is a need to establish systems for identifying risk factors and developing incident response systems for increased security (Figure 2.4.4).

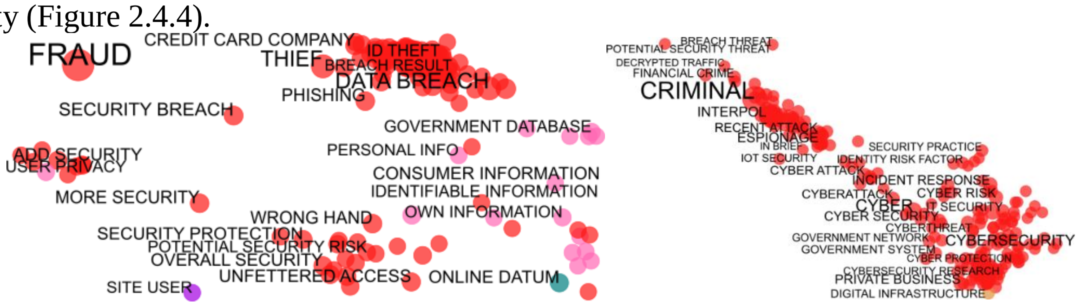


Figure 2.4.4. "Identity security" (left) and "Cybersecurity" (right)

In parallel to security issues, privacy issues emerge as important concerns in the widespread use of ICTs. Most of the topics related to privacy issues addresses policy measures, regulations and law in relation to privacy (Figure 2.4.5).

Figure 2.4.5. "Privacy issues"

Developments in ICTs create ethical dilemmas, and appropriate social and technological responses to be developed to tackle with them in terms of processes, policy initiatives and frameworks, data access and information sharing, technology solutions and legislation. Another aspect of the ethics concerns publication and sharing of information through media. With the widespread sharing of information through online and social media channels, it is getting more and more difficult to distinguish real news and stories from the fake ones. These create mixed social reactions to developments, which are shared by reliable as well as unreliable sources of information. Therefore,

[4] https://www.gartner.com/en/newsroom/press-releases/2018-08-15-gartner-forecasts-worldwide-information-security-spending-to-exceed-124-billion-in-2019

trust factor plays an important role in media and raises concerns about preventing the dissemination of fake news and information over ICT networks, for which there is no clear solution so far (Figure 2.4.6).

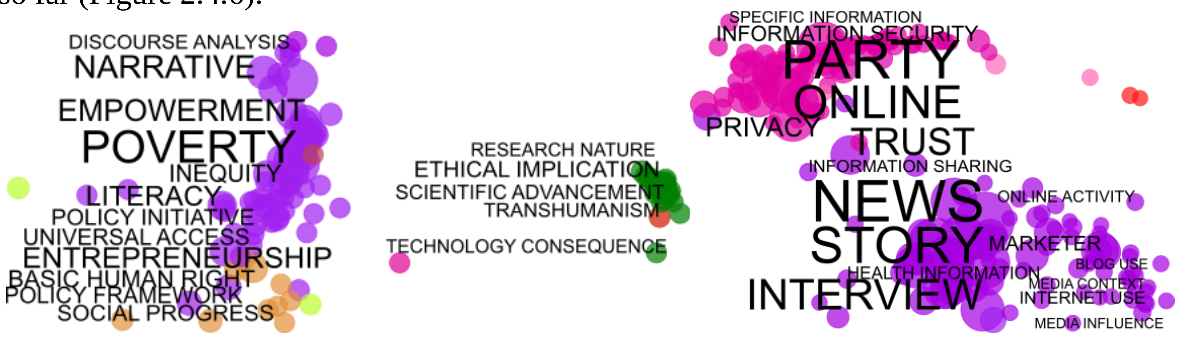


Figure 2.4.6. "Ethical issues of ICT" (left) and "Media, news and trust" (right)

IT2: Internet Access & the Network & Information Infrastructure

Accessing to the Internet and information infrastructure is crucial to exploit the opportunities offered by the digitalization process and digital economy. Two topics emerging related to this thrust are broadband access and cloud based systems. Broadband access is important to make sure that large groups of the population both in urban and rural areas have access to the Internet in a fast, secure and affordable way. There is a need to develop necessary telecom infrastructure, and provide broadband services for all. In addition to the Internet access, the storage of information is also an important issue. Cloud systems have been developed for making applications, services and resources available to large amount of users on demand via the Internet from a cloud computing providers' servers. Cloud services also require investments in infrastructures with servers, data centers and applications (Figure 2.4.7).

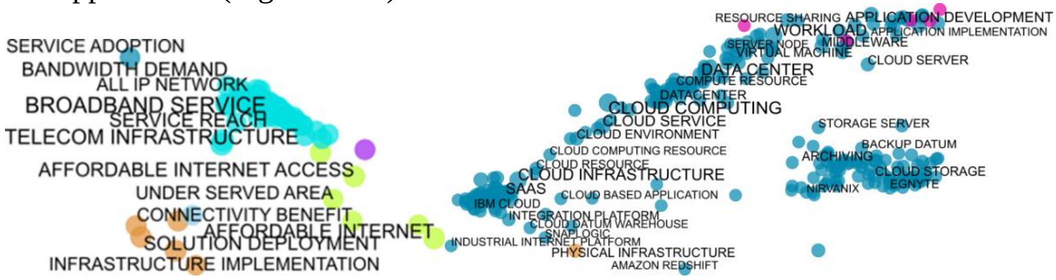


Figure 2.4.7. "Broadband access promotion" (left) and "Cloud based systems" (right)

IT3: Big Data, Data Analytics and Decision Support

Increased amount of data and advancements in data analytics made the use of big data as a new source of evidence for decision-making. Two points related to this thrust are concerned with the collection of data. With the reduced cost of sensors and widespread implementation of wireless networks, large amount of information are collected related to climate, transportation, agriculture, health and all other sectors of the social and economic life. Besides collection of the historical data, there is now an increasing need and possibilities for collecting information real time to enable real time decision-making. A real time data collection system will require infrastructure for networks and communication systems, wireless networks as well as systems for processing data (Figure 2.4.8).

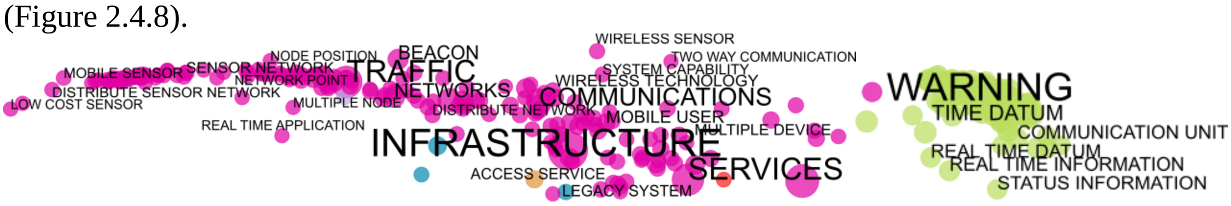


Figure 2.4.8. "Sensor networks and wireless infrastructure" (left) and "Real time data" (right)

Data collected and processed need to be analyzed through the big data analytics systems. This is certainly an area where South Africa, like many other countries in the world, should develop necessary skills, capacity and infrastructure. Systems to be developed include data collection, storage, processing, analytics, visualization, and interpretation. A number of new skills will be required for the big data analytics systems including machine learning expert, data scientist, analyst, domain experts, and programmers (Figure 2.4.9).

Figure 2.4.9. "Big data analytics" (left) and "Decision support" (right)

In order to build necessary skills and capacity for a digital future, ICTs should be increasingly integrated into education systems. For instance coding and big data analytics can be included in the curricula of tertiary schools, if not primary and secondary (Figure 2.4.10).

Figure 2.4.10. "IT in education"

IT4: Smart and sustainable municipal service delivery

Information and Communication Technologies are also instrumental in terms of implementing smart cities, energy, transport and public services. A smart city refers to the use of ICTs to increase operational efficiency, information sharing and use, and service delivery to improve quality of life of citizens and provide sustainable systems with smart solutions. Smart energy use and transportation systems are two out of many other application areas for smart cities. Besides them, there are also technologies and applications for smart homes and buildings. The key enabling technology of these smart systems is the Internet of Things (IoT). It is expected that these technologies will find application areas not only in cities but also to improve quality of life in rural areas with better access to products, services and clean energy and efficient transport systems with smart and integrated solutions (Figure 2.4.11).

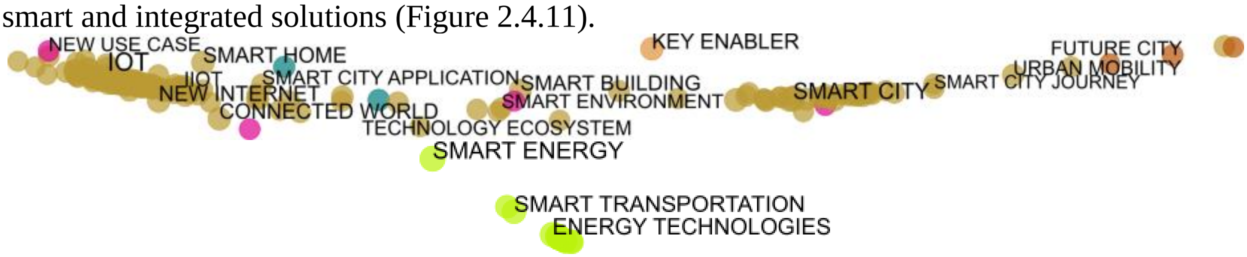


Figure 2.4.11. "Smart systems (city, energy, transport)"

Regarding smart energy systems, a number of topics arise around use of green energy sources, energy saving solutions, smart grid systems and energy information and management systems. Policy structures, energy infrastructure, and utility companies need to be upgraded in order to implement smart energy solutions (Figure 2.4.12).

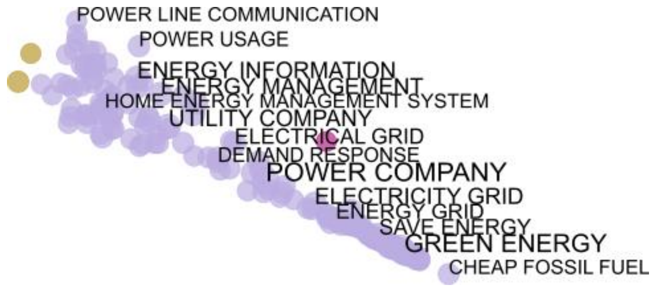


Figure 2.4.12. “Energy, electricity and utilities”

Implementing individual smart solutions certainly is not sufficient for setting up ‘smart systems’. Smart governance is also needed for integrating and operating those components. Governance at the national, regional and local levels should be adapted to smart systems with the development of necessary public sector institutions, raising investments, and involving enterprises in the process. The iFORA system also picked up the development of smart payment methods and digital currencies associated to the development of smart and sustainable municipal service delivery thrust (Figure 2.4.13).

Figure 2.4.13. “Smart governance” (left) and “Cryptocurrency” (right)

Dynamics of “ICT” domain thrusts

Dynamics of the “ICT” domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts IT1 (Checks and balances for a digital future) appears to be the highest on the agenda (Figure 2.4.14). The emphasis on big data, analytics and decision support (IT3) is growing, however, this growth is still insignificant. Use of ICTs for smart and sustainable municipal service delivery (IT4) is considerably low.

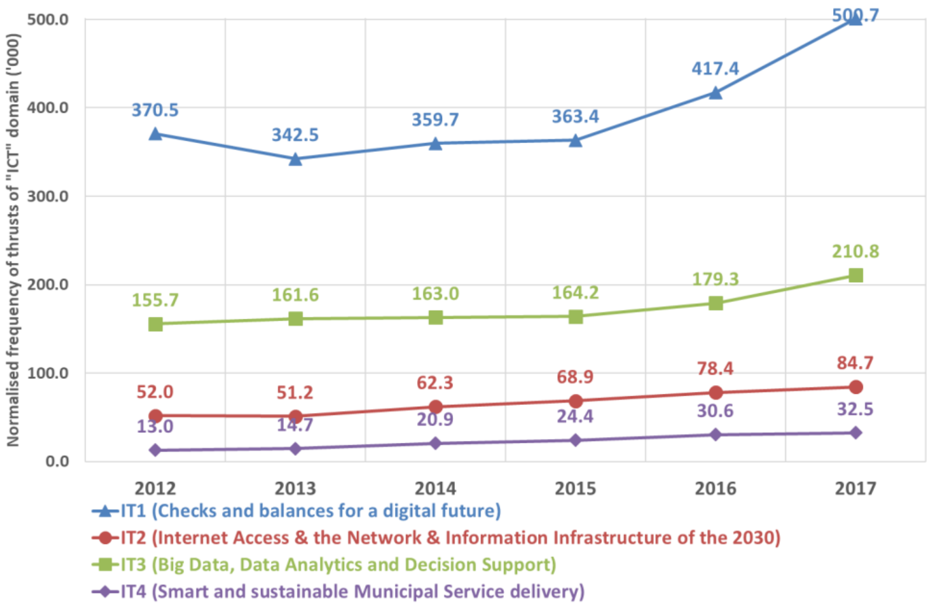


Figure 2.4.14. Normalized frequency of all terms related with thrusts of “ICT” domain ('000) in 2012 – 2017

Note: “Normalized frequency” for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.4.4 illustrates to what extent the "ICT" domain thrusts address the challenges. Job creation, population growth and rural communities appear to be challenges linked to ICT thrusts.

Table 2.4.4. Impacts of all thrusts of "ICT" domain on challenges

Challenges	ICT			
	IT1	IT2	IT3	IT4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	1.0	0.0	0.0	0.0
Affordable Food	7.0	0.0	2.0	0.0
Carbon Emission Reduction	2.0	4.0	0.0	8.0
Clean Water Access	0.0	2.0	0.0	0.0
Crime Prevention	3.4	0.0	1.5	0.0
Crime Reduction	13.0	0.0	0.0	0.0
Economy Growth	0.0	0.0	0.0	1.0
Employment Growth	7.0	1.0	3.0	1.5
Export Growth	2.0	0.0	0.0	2.0
High Living Standard	1.0	0.0	0.0	1.0
High Quality Health Care Service	3.0	0.0	0.0	0.0
Income Growth	2.5	0.0	0.0	0.0
Job Creation	35.5	14.7	31.0	61.0
Low Greenhouse Gas Emission	0.0	0.0	0.0	0.0
Low Mortality	7.0	5.0	1.0	0.0
Population Growth	37.7	14.0	7.0	18.5
Poverty Alleviation	4.0	1.0	1.5	26.0
Reduce Water Demand	0.0	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0	2.0
Rural Community	16.0	28.7	9.0	21.0
Secure Water Supply	0.0	0.0	0.0	1.0
Skill Improvement	1.0	0.0	1.0	0.0
Universal Broadband Access	1.0	1.5	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust IT1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.5. HEALTH TECHNOLOGY TO PREVENT ILL-HEALTH, AND ADVANCE WELL-BEING FOR MARGINALIZED (HEALTH)

Overall description of the domain

Within the scope of the South African National STI Foresight 2030, the Health domain refers to technologies and strategies to prevent and treat ill health while advancing well-being for marginalized. Overall, the health system needs to be optimized in order to deliver better diagnostic and treatment services and for the overall improvement of the healthcare system as well as drug development. An understanding needs to be developed in the society that prevention is cheaper than cure, so that people have better control over their own health. There is also need to develop current health infrastructure and administration, which are inadequate, particularly in the rural areas of South Africa. Like in other domains, emerging technologies including mobile technologies, AI and Big Data will bring enormous opportunities for the development of the healthcare service delivery for all.

Overview of research potential of South Africa in "Health" domain

Figure 2.5.1 shows that there is a growing scientific emphasis on the Health domain in South Africa. The number of publications in this domain the Health domain is considerably high compared to other STI domains identified in the National STI Foresight 2030 study. The number of publications has been growing continuously as well as the share of South Africa in the global scientific output in this domain.

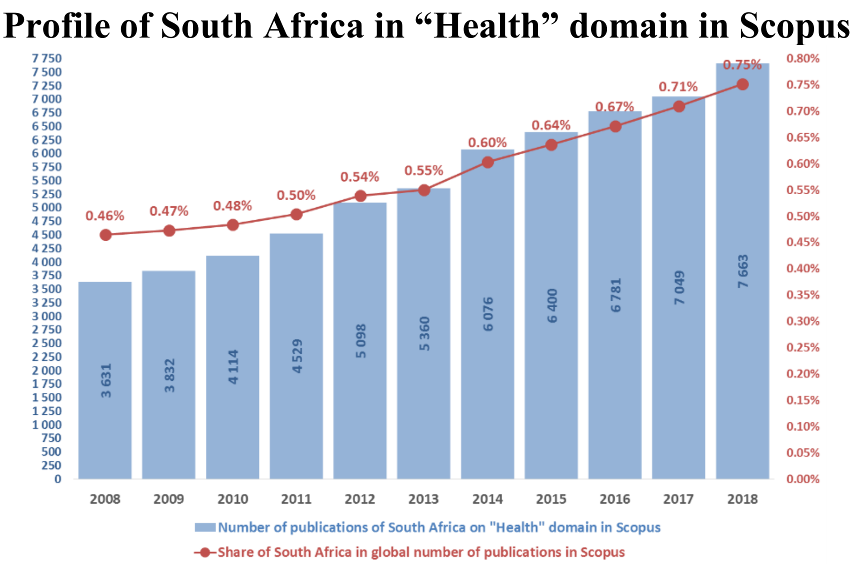


Figure 2.5.1. Dynamics of publications of South Africa on "Health" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.5.2 shows the leading countries in the Health domain. Although in terms of number of publications this domain appears to be one of the leading STI areas in South Africa, compared to the rest of the world, there is still a considerable progress the country needs to make. The country is currently positioned at the 31st place in the world.

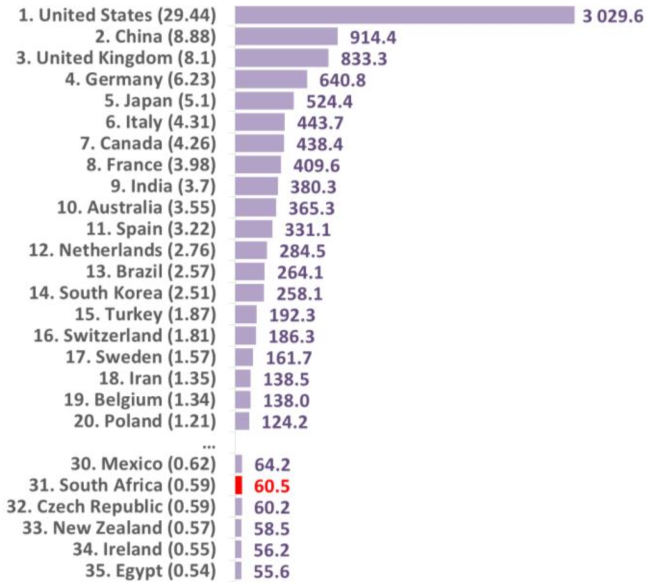


Figure 2.5.2. Leading countries by number of publications in "Health" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Australia, the Netherlands and Canada (Table 2.5.1). Nigeria, Kenya, Uganda, Ghana and Zimbabwe are among the key African scientific collaborators.

Table 2.5.1. Key partner countries of South Africa in internationally collaborated publications in "Health" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	13593	42.39%
United Kingdom	9168	28.59%
Australia	3895	12.15%
Netherlands	3343	10.42%
Canada	3156	9.84%
Germany	3022	9.42%
Switzerland	2750	8.58%
France	2475	7.72%
Belgium	2146	6.69%
India	1897	5.92%
Italy	1790	5.58%
Sweden	1780	5.55%
Nigeria	1681	5.24%
Spain	1617	5.04%
Brazil	1436	4.48%
Kenya	1305	4.07%
China	1120	3.49%
Norway	1101	3.43%
Uganda	1041	3.25%
Denmark	1020	3.18%
Japan	879	2.74%
Ghana	846	2.64%
New Zealand	822	2.56%
Zimbabwe	777	2.42%
Thailand	766	2.39%
Cameroon	700	2.18%
Argentina	668	2.08%

Tanzania	660	2.06%
Malawi	641	2.00%
Austria	598	1.86%
Zambia	590	1.84%
Mexico	581	1.81%
Poland	577	1.80%
Ireland	571	1.78%
Finland	570	1.78%
Israel	559	1.74%
Saudi Arabia	522	1.63%
Portugal	501	1.56%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.5.2 shows the leading organizations in South Africa publishing in the domain of Health with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output. University of Cape Town appears to have a significant capacity in publishing in the Health domain.

Table 2.5.2. Leading organizations of South Africa by number of publications in "Health" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of Cape Town	13636	22.53%
University of Witwatersrand	9766	16.13%
Universiteit Stellenbosch	8345	13.79%
University of KwaZulu-Natal	7148	11.81%
Universiteit van Pretoria	6177	10.20%
South African Medical Research Council	4988	8.24%
North-West University	2952	4.88%
Groote Schuur Hospital	2427	4.01%
National Health Laboratory Services	2424	4.00%
University of the Western Cape	2081	3.44%
University of the Free State	1717	2.84%
University of Cape Town, Faculty of Health Sciences	1677	2.77%
The Nelson R. Mandela Medical School	1536	2.54%
University of Johannesburg	1529	2.53%
Tygerberg Hospital	1262	2.08%
National Institute for Communicable Diseases	1190	1.97%
Red Cross War Memorial Children's Hospital	1183	1.95%
University of South Africa	1153	1.90%
University of Limpopo	1019	1.68%
Human Sciences Research Council of South Africa	927	1.53%
Sefako Makgatho Health Sciences University SMU	861	1.42%
University of Fort Hare	843	1.39%
Rhodes University	826	1.36%
Baragwanath Hospital	715	1.18%
Tshwane University of Technology	644	1.06%
The Council for Scientific and Industrial Research	553	0.91%
University of the Witwatersrand, Faculty of Health Sciences, School of Pathology	551	0.91%
Nelson Mandela Metropolitan University	533	0.88%
Cape Peninsula University of Technology	523	0.86%
Centre for the AIDS Programme of Research in South Africa	521	0.86%
University of Venda for Science and Technology	464	0.77%
Walter Sisulu University	454	0.75%
Durban University of Technology	441	0.73%
National Research Foundation	424	0.70%
Africa Centre for Health and Population Studies	423	0.70%

Agricultural Research Council, Pretoria	400	0.66%
Inkosi Albert Luthuli Central Hospital	365	0.60%
Onderstepoort Veterinary Institute	279	0.46%
University of Cape Town Lung Institute	268	0.44%
University of the Witwatersrand, Faculty of Health Sciences, School of Clinical Medicine	248	0.41%
University of the Free State, School of Medicine	227	0.38%
University of Zululand	227	0.38%
University of the Witwatersrand, Faculty of Health Sciences	207	0.34%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Health" domain

This section describes the "Health Technology to Prevent and Treat Ill-Health, and Advanced Well-Being, for Marginalized (HE)" domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Figure 2.3.3 shows the Health domain with its clusters and interrelations to each other. A detailed analysis of Figure 2.5.3 provides an overview of HE thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.5.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.5.3. "Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized (HE)" thrusts and topics

HE Thrusts	**Topics emerging under each thrust**
HE1: Optimization of health systems	"Rapid diagnostic" and "Diagnostic tools" (Fig. 2.5.4)
	"Medical treatment" and "Patient treatment" (Fig. 2.5.5)
	"Healthcare system" and "Drug development" (Fig. 2.5.6)
HE2: Improving the quality of health care	"Birth care and child care" (Fig. 2.5.7)
	"Intensive care" (Fig. 2.5.8)
	"Healthcare organization management" (Fig. 2.5.9)
	"Healthcare staff issues" (Fig. 2.5.10)
	"Healthcare policy" (Fig. 2.5.11)
	"Health care economics" (Fig. 2.5.12)
	"Health care access" (Fig. 2.5.13)
	"Health care quality" and "Management of clinics" (Fig. 2.5.14)
	"Personalized medicine" and "Cancer treatment" (Fig. 2.5.15)
HE3: Digitization of health systems	"Hospital records" and "Patient records" (Fig. 2.5.16)
	"Heath information system" and "Health database" (Fig. 2.5.17)
	"Telemedicine", "Mobile medicine", and "Robotics" (Fig. 2.5.18)

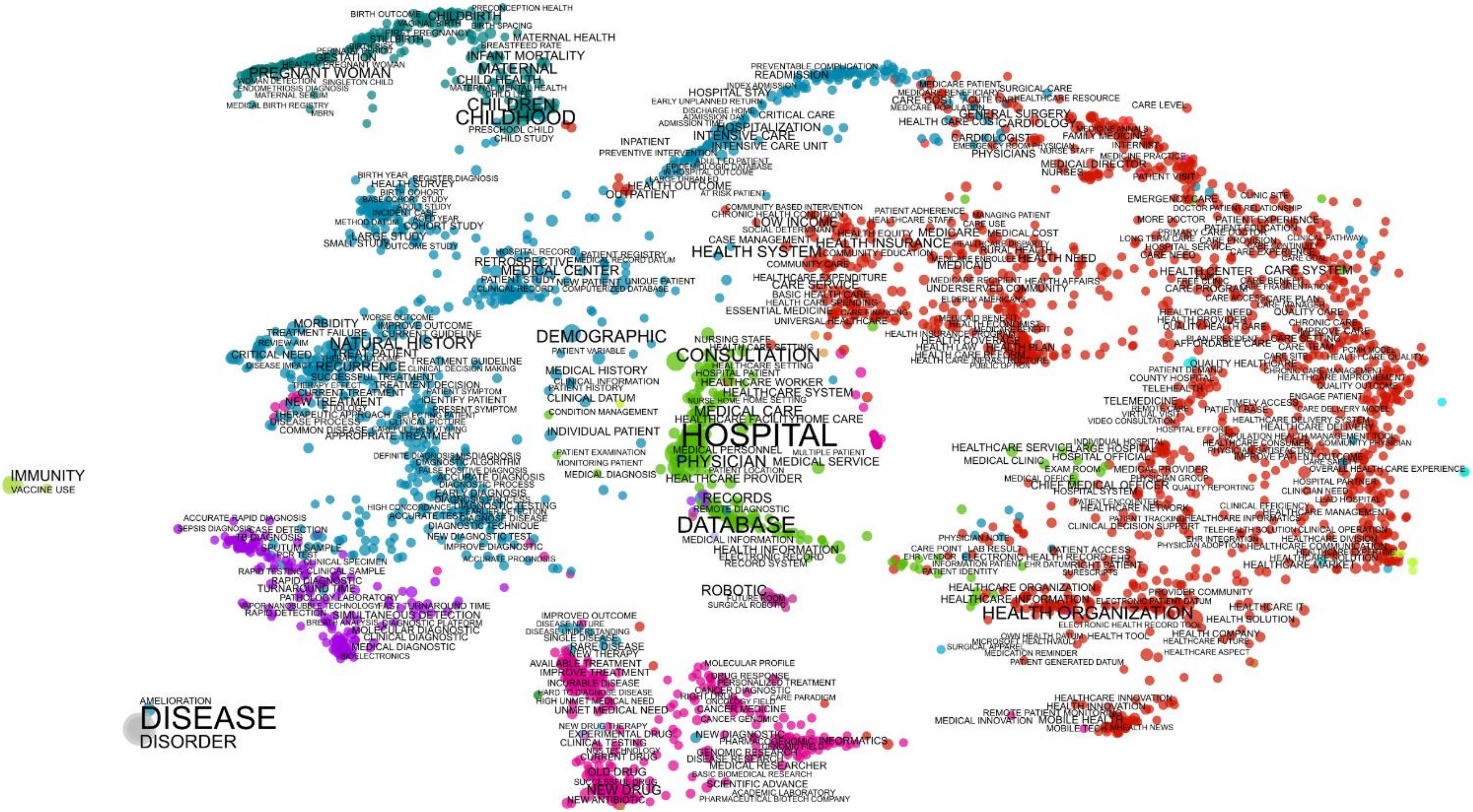


Figure 2.5.3. “Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized” domain full semantic map for 2014-2018

“Health Technology to Prevent and Treat Ill-Health, and Advance Well-Being, for Marginalized” Thrusts

HE1: Optimization of health systems

The analysis of the “optimization of health systems” thrust revealed six topics regarding diagnostic, treatment, and overall improvement of the healthcare system as well as drug development. In terms of diagnostics, rapid diagnostic systems are gaining importance. The cluster on this topic includes issues on different levels of diagnostics (clinical, medical or molecular), development of diagnostic platforms, sample collection methods and various technologies to be used for this purpose (including Bioelectronics and vapor nanobubble technologies (Figure 2.5.4 left). In relation to that, Figure 2.5.4. (right) presents various issues concerning diagnostics tools, and new methods and techniques for increasing accuracy.

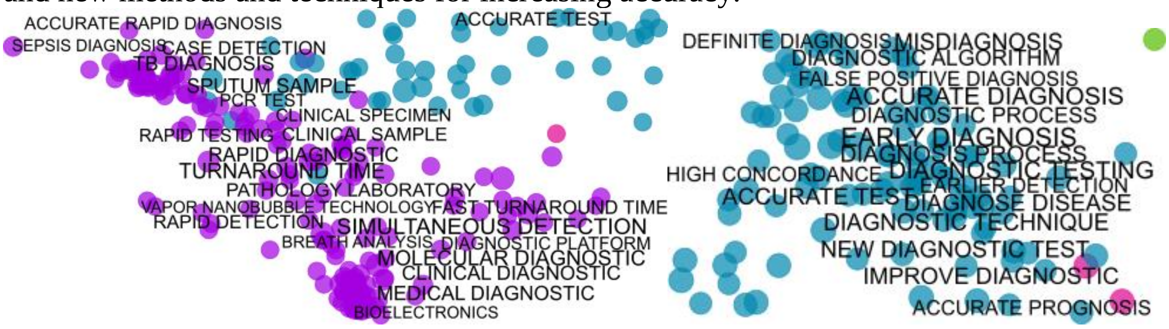


Figure 2.5.4. “Rapid diagnostic” (left) and “Diagnostic tools” (right)

Following the diagnosis, treatment comes as an important topic for the optimization of the health systems. The advancement of new technologies brings new methods and approaches for treatment. There is a need to improve patient examination methods, keep clinical information and patient history, with the help of the ICT systems, and monitor patients’ health conditions regularly (Figure 2.5.5.).

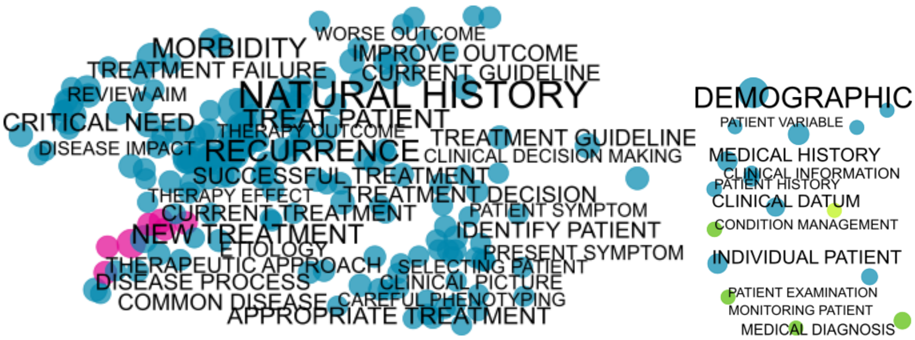


Figure 2.5.5. “Medical treatment” (left) and “Patient treatment” (right)

Besides improvements in diagnostics and treatment, the optimization of the health systems also requires its upgrading. These upgrades require substantial improvements in the hospitals and healthcare facilities, skills of the healthcare personnel, and the quality of the medical services. Home care also appears to be an important point for the development as a part of the healthcare system (Figure 2.5.6 left). Drugs are vital components of the healthcare. Development and use of new drugs will certainly have transformative effects on the healthcare system. The issues around the new drugs are populated around experiments and clinical testing of drugs and their successful use in therapy. The antibiotic use in the world is also a big debate in health circles. Development of new antibiotics also appears as a branch in new drug development activities (Figure 2.5.6 right).

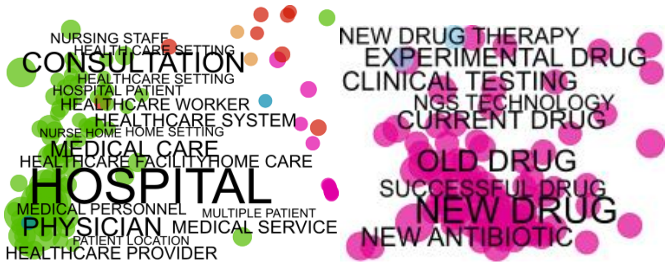


Figure 2.5.6. “Healthcare system” (left) and “Drug development” (right)

HE2: Improving the quality of healthcare

In addition to the optimization of the healthcare services, the second thrust of the HE domain is concerned with the improvement of the quality of the healthcare. A number of topics emerge regarding to this thrust ranging from the development of care from the birth to a comprehensive overhaul of the healthcare system from the way it is organized, staff employed, its economic aspects, quality, efficiency and access. These are described in the consecutive maps presented below. Children health is immensely important for a health population. Most of the diseases can be prevented already from the pregnancy stages of mothers. Reduced infant mortality is an important indicator of development. Therefore necessary healthcare should be provided for women and parents from the pregnancy and maternity stage to early and late childhood (Figure 2.5.7).

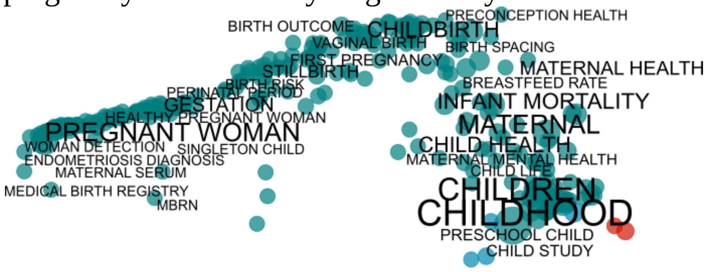


Figure 2.5.7. “Birth care and child care”

Another aspect of healthcare to be developed is intensive care. There are a range of issues to be considered starting from the admission to intervention, hospital stay and discharge (Figure 2.5.8).

Figure 2.5.8. “Intensive care”

Besides the issues related to care, the improvement of healthcare requires transformations in the healthcare systems, which require action at multiple aspects. Beginning with the management of healthcare organizations, there are possibilities of using ICTs to implement and widespread use of electronic health records and patient data. These technologies, along with the application of personal health systems, are expected to make revolutionary changes in the way healthcare services are organized and delivered (Figure 2.5.9).

Figure 2.5.9. "Healthcare organization management"

Healthcare staff, including physicians, surgeons, cardiologists and nurses among the others, needs necessary skills and capabilities to keep up with the developments in the healthcare system. Particularly skills related to the use of ICTs and health data as well as new technologies for diagnosis, treatment, surgery etc. seem to be important (Figure 2.5.10).

Figure 2.5.10. "Healthcare staff issues"

Healthcare system also needs to be regulated with appropriate policy measures in order to be improved. Among the important aspects for regulation are access to the healthcare system and equity, management of healthcare costs, making healthcare more affordable for low income populations, health insurance, and community care among the others illustrated in Figure 2.5.11.

Figure 2.5.11. "Healthcare policy"

As mentioned in the policy aspect, the availability and accessibility of healthcare services from the economic point of view come out as an important issue for the improvement of the healthcare systems. Reduction of the healthcare expenditures is a first step for accessing to basic healthcare services for the marginalized parts of the society. Meanwhile, it is important to reduce the burden of the healthcare spending on the economic system. This requires a more systemic approach, which relates to other STI domains, such as nutrition. With better nutrition of the population, the society will be healthier with less health problems. This is also related to education systems, economic systems and access to information and technology systems. Therefore, there is a need to have a systemic perspective when economic and policy aspects of healthcare are dealt with (Figure 2.5.12).

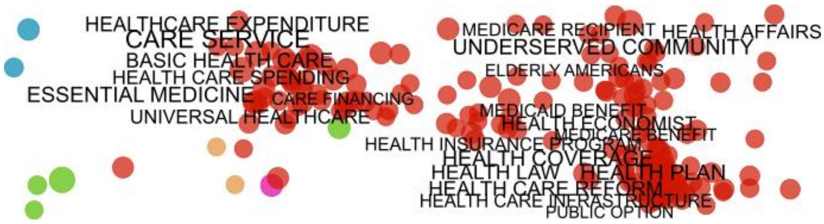


Figure 2.5.12. "Health care economics"

Improved healthcare systems also mean accessible healthcare services for all layers of the society. There are a number of issues to be considered in terms of access, including income levels, medical costs, community care, disparity in healthcare and equity. Necessary insurance systems should be in place also for the marginalized to access healthcare services (Figure 2.5.13).

Figure 2.5.13. "Health care access"

While delivering healthcare services, besides their economy, the quality aspect should also be considered. Availability of medical personnel, improved infrastructure and services, patient experience are among the important determinants of the quality in healthcare. There is also a need for the efficient management of the clinics in order to maintain the quality of services (Figure 2.5.14).

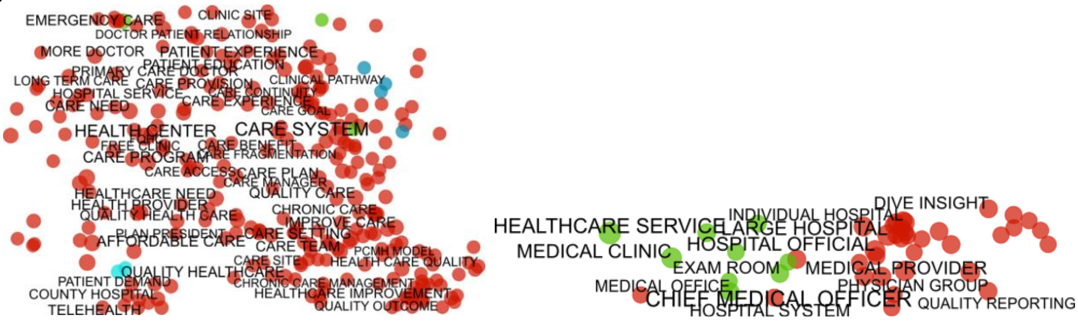


Figure 2.5.14. "Health care quality" (left) and "Management of clinics" (right)

Improving healthcare quality is also directly related to the development of personalized medicine, where medical services, practices, interventions and products are tailored to the individual patients based on their characteristics. Research in areas like genomics and pharmagenomics plays important role for personalized medicine. One of the areas where personalized medicine can play a significant role is cancer research, where personalized treatment is needed from the diagnostic stages to drug response (Figure 2.5.15).

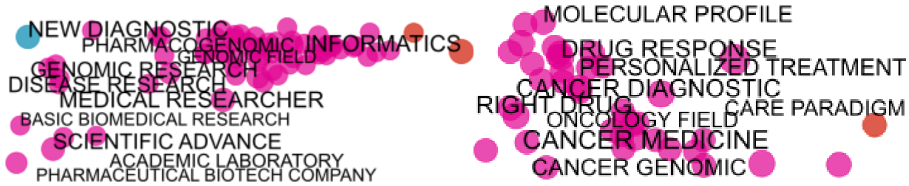


Figure 2.5.15. "Personalized medicine" (left) and "Cancer treatment" (right)

HE3: Digitization of health systems

The digitalization of health systems provides enormous opportunities for the optimization of healthcare services and increasing their quality. Electronic health records are one of the major application areas for the digitalization of health systems. Clinical records should be collected in a database in safe and secure ways by considering the privacy and ethical aspects. Necessary computer infrastructures need to be established with ICT skills in place (Figures 2.5.16 and 2.5.17).

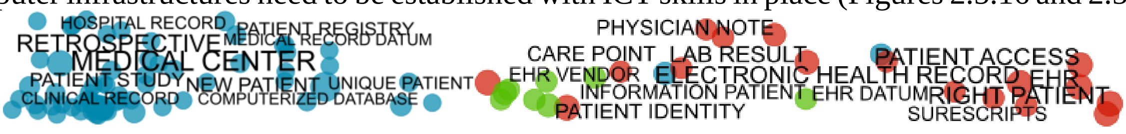


Figure 2.5.16. "Hospital records" (left) and "Patient records" (right)

Figure 2.5.17. "Heath information system" (left) and "Health database" (right)

Recent years have also seen increasing possibilities for telemedicine, which allows caring for patients remotely when the healthcare provider and patient are not physically present with each other. Video consultations and virtual visits are technological alternatives as they enable remote care. Associated to the telemedicine concept is mobile medicine, which also serves for the remote delivery of healthcare services. The use of robotics in recent years moved telemedicine to a new dimension enlarging the services delivered from mere consultations to remote surgeries (Figure 2.5.18).

Figure 2.5.18. "Telemedicine" (left), "Mobile medicine" (center), and "Robotics" (right)

Dynamics of "Health" domain thrusts

In this section, the dynamics of the "Health" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts HE1 (Optimization of health systems) and HE2 (Improving the quality of health care) appear to the highest on the agenda (Figure 2.5.19). Digitization of health systems (HE3) is still not given sufficient attention in the Health domain.

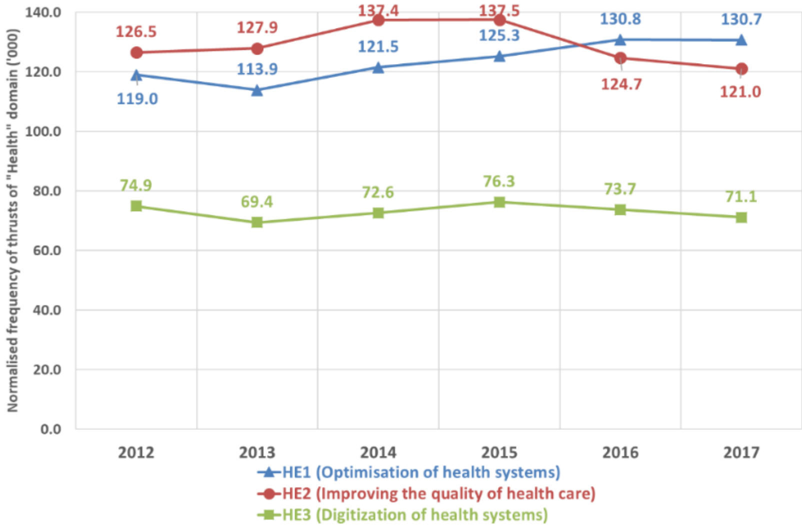


Figure 2.5.19. Normalised frequency of all terms related with thrusts of "Health" domain ('000) in 2012 – 2017

Note: "Normalised frequency …" for a specific thrust – is a total normalised number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year

Furthermore, Table 2.5.4 illustrates to what extent the "Health" domain thrusts address the challenges. In parallel to the other STI domains, the thrusts of the Health domain are strongly linked to rural community, job creation and population growth.

Table 2.5.4. Impacts of all thrusts of "Health" domain on challenges

Challenges	Health		
	HE1	HE2	HE3
Affordable Education	1.0	0.0	0.0
Affordable Energy	0.0	1.5	0.0
Affordable Food	1.0	4.5	0.0
Carbon Emission Reduction	0.0	0.0	0.0
Clean Water Access	1.0	1.0	0.0
Crime Prevention	1.0	2.0	1.0
Crime Reduction	2.5	1.0	0.0
Economy Growth	1.0	0.0	0.0
Employment Growth	4.5	1.0	1.0
Export Growth	0.0	1.0	1.0
High Living Standard	4.0	2.0	1.5
High Quality Health Care Service	3.5	2.0	1.0
Income Growth	0.0	2.0	0.0
Job Creation	14.2	15.2	26.0
Low Greenhouse Gas Emission	0.0	1.0	0.0
Low Mortality	3.3	9.8	6.0
Population Growth	17.8	28.7	1.3
Poverty Alleviation	2.0	1.0	3.0
Reduce Water Demand	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0
Rural Community	34.3	13.0	73.6
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	1.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust HE1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.6. SUSTAINABLE ENERGY TECHNOLOGIES FOR THE MARGINALIZED (ENERGY) DOMAIN

Overall description of the domain

With the advancement of societies, energy has become one of the basic human needs for a sustained and uninterrupted life. Although large cities in South Africa has a relatively stable energy supply, both rural and peri-urban marginalized communities suffer from accessing energy. Clean and affordable energy sources such as the harvesting of solar, wind and bio energy provide opportunities for marginalized communities to adopt these new technologies, as there is no overhead due to the replacement of old technologies. Sustainable energy technologies can leapfrog old technologies and their many limitations. Possibilities for local sustainable energy production will give communities independence, self-sufficiency and cooperation towards a common good. Decentralized local energy sources will reduce dependence on the national grid and create economic opportunities for the marginalized across South Africa. Thus, the Energy domain focuses on clean, affordable and renewable energy solutions, energy efficiency and distributed generation.

Overview of research potential of South Africa in "Energy" domain

Figure 2.6.1 shows that there is a growing scientific emphasis on the Energy domain in South Africa. The number of publications has been growing rather faster compared to other STI domains. However, the share of South Africa's contribution in the global scientific output is still relatively low (under 1%).

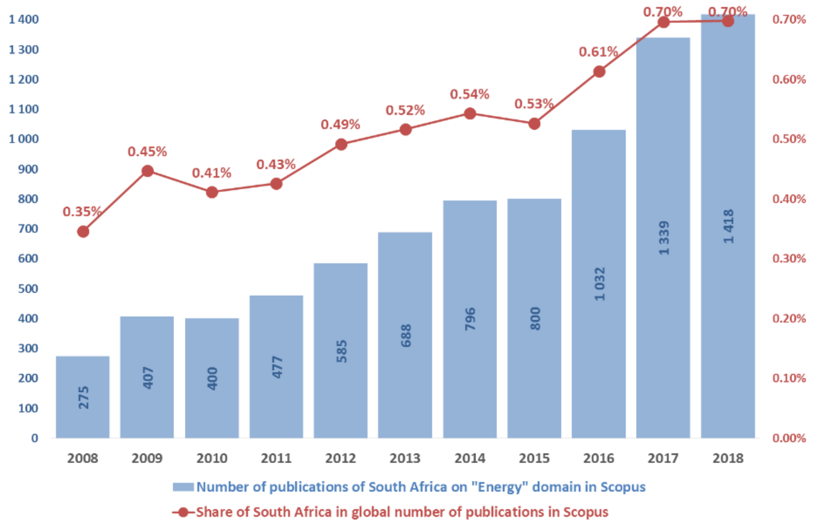


Figure 2.6.1. Dynamics of publications of South Africa in "Energy" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.6.2 shows the leading countries in the Energy domain.

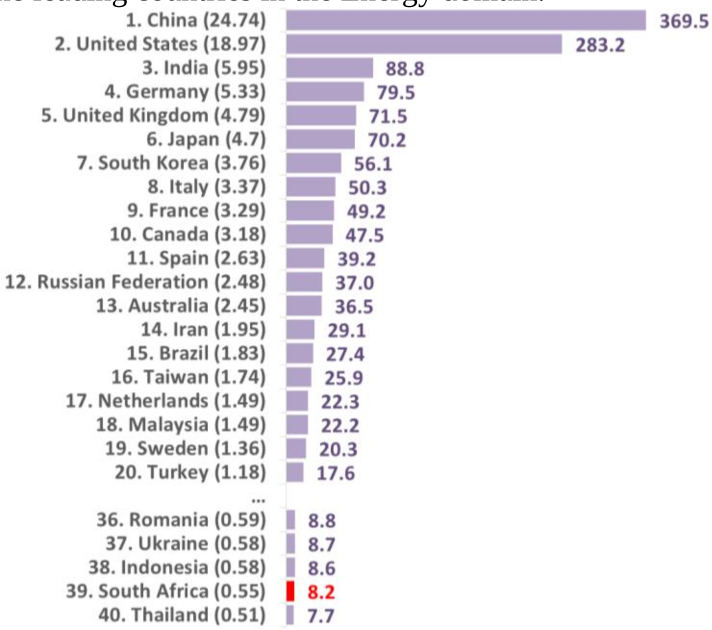


Figure 2.6.2. Leading countries by number of publications ('000) in "Energy" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among those countries, the key partners of South Africa are the United States, the United Kingdom, Germany, India and France. Collaboration with Nigeria is relatively high with the 7th position among the top collaborators (Table 2.6.1).

Table 2.6.1. Key partner countries of South Africa in internationally collaborated publications in "Energy" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	756	21.97%
United Kingdom	519	15.08%
Germany	397	11.54%
India	396	11.51%
France	328	9.53%
Australia	287	8.34%
Nigeria	277	8.05%
China	259	7.53%
Italy	240	6.97%
Canada	224	6.51%
Netherlands	195	5.67%
Iran	129	3.75%
Sweden	129	3.75%
Norway	107	3.11%
Spain	105	3.05%
Denmark	103	2.99%
Brazil	98	2.85%
Japan	97	2.82%
Poland	95	2.76%
Switzerland	85	2.47%
Austria	82	2.38%
Belgium	80	2.32%
Russian Federation	78	2.27%
Chile	75	2.18%

Finland	73	2.12%
New Zealand	68	1.98%
Saudi Arabia	63	1.83%
Malaysia	59	1.71%
Ireland	58	1.69%
Kenya	52	1.51%
Turkey	52	1.51%
Namibia	50	1.45%
Zimbabwe	50	1.45%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.6.2 shows the leading organizations in South Africa publishing in the domain of Energy with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.6.2. Leading organizations of South Africa by number of publications in "Energy" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of Cape Town	954	11.61%
Universiteit van Pretoria	916	11.15%
University of KwaZulu-Natal	816	9.93%
University of Johannesburg	778	9.47%
North-West University	758	9.22%
Universiteit Stellenbosch	733	8.92%
University of Witwatersrand	553	6.73%
Tshwane University of Technology	463	5.63%
The Council for Scientific and Industrial Research	426	5.18%
University of the Western Cape	289	3.52%
University of South Africa	271	3.30%
Cape Peninsula University of Technology	251	3.05%
Durban University of Technology	161	1.96%
University of the Free State	161	1.96%
Eskom	149	1.81%
Nelson Mandela Metropolitan University	120	1.46%
Central University of Technology, Free State	108	1.31%
University of Fort Hare	107	1.30%
Vaal University of Technology	107	1.30%
Rhodes University	103	1.25%
University of Witwatersrand, School of Chemical and Metallurgical Engineering	98	1.19%
Sasol Technology Pty Ltd	87	1.06%
Pebble Bed Modular Reactor Pty Limited	74	0.90%
NECSA	63	0.77%
University of Venda for Science and Technology	58	0.71%
University of Limpopo	55	0.67%
Meraka Institute	54	0.66%
National Research Foundation	50	0.61%
Ithemba Laboratory for Accelerator-Based Sciences	47	0.57%
Mangosuthu University of Technology	41	0.50%
University of Zululand	38	0.46%
University of KwaZulu-Natal School of Chemical Engineering	36	0.44%
South African Astronomical Observatory	34	0.41%
Mintek	27	0.33%
Agricultural Research Council, Pretoria	26	0.32%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of “Energy” domain

This chapter describes the “Sustainable Energy Technologies for the Marginalized” domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The second section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.6.3 shows the entire domain of “Sustainable Energy Technologies for the Marginalized (EN)” with its clusters and interrelations to each other. A detailed analysis of Figure 2.6.3 provides an overview of EN thrusts and a number of existing and emerging topics for consideration under each of them. These are presented in Table 2.6.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.6.3. “Sustainable Energy Technologies for the Marginalized” thrusts and topics

EN Thrusts	Topics emerging under each thrust
EN1: Clean, affordable and sustainable energy for all	“Conventional energy sources” (Fig. 2.6.4)
	“Clean and renewable energy” (Fig. 2.6.5)
	“Bioenergy” (Fig. 2.6.6)
	“Energy policy” (Fig. 2.6.7)
	“Carbon emissions policy” (Fig. 2.6.8)
	“Energy costs and tariffs” (Fig. 2.6.9)
EN2: Renewable Energy sources and technologies	“Solar energy” (Fig. 2.6.10)
	“Wind energy” (Fig. 2.6.11)
EN3: Energy efficiency solutions for industry plus household use	“Energy efficiency” (Fig. 2.6.12)
	“Energy system” (Fig. 2.6.13)
EN4: Distributed energy generation and storage	“Distributed energy generation” (Fig. 2.6.14)
	“Grid energy generation” (Fig. 2.6.15)

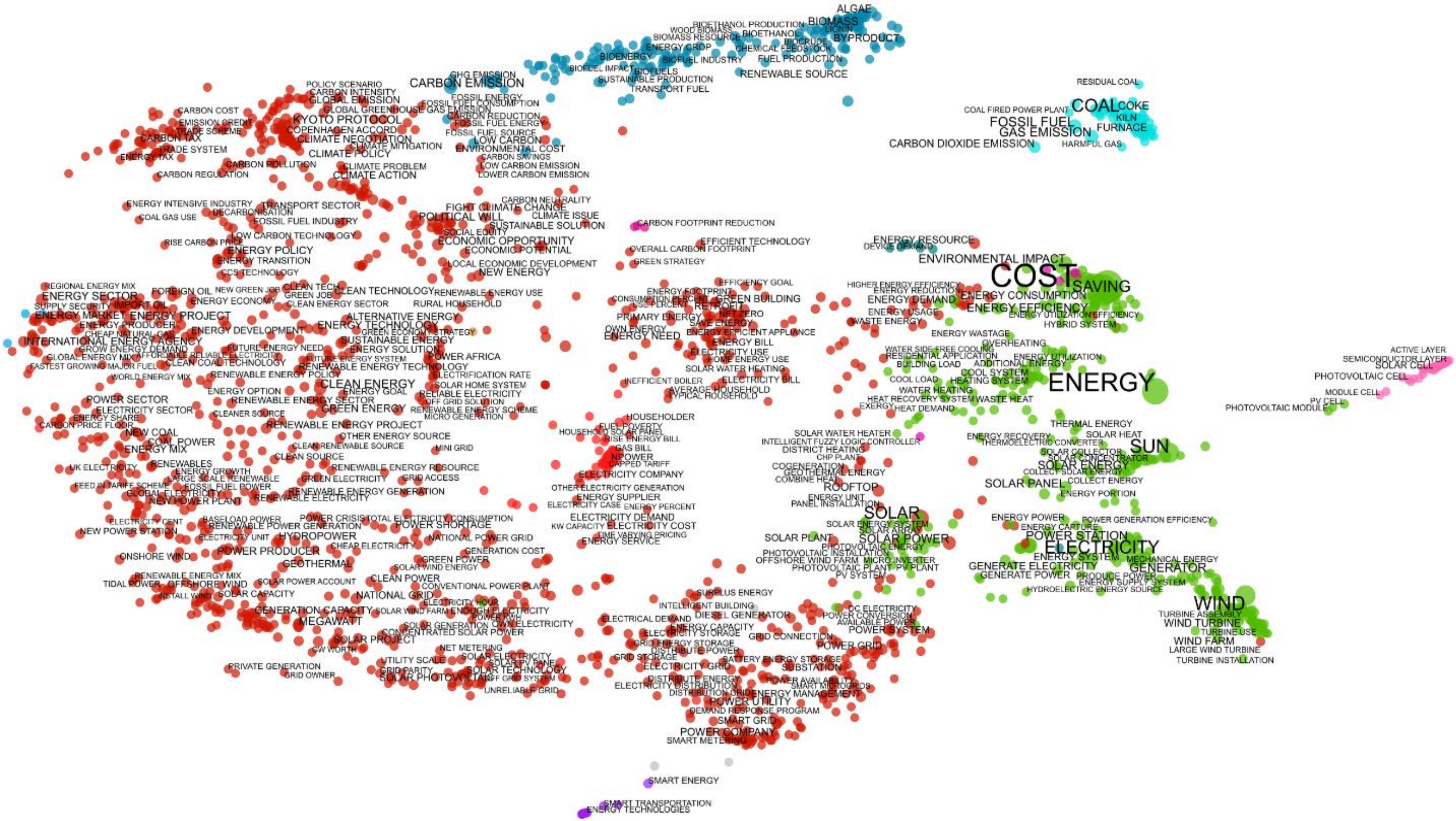


Figure 2.6.3. "Sustainable Energy Technologies for the Marginalized" domain full semantic map for 2014-2018

"Sustainable Energy Technologies for the Marginalized" Thrusts

EN1: Clean, affordable and sustainable energy for all

Although renewable energy sources are used increasingly, it is expected that the conventional sources of energy will still have a considerable proportion in the energy mix in the next few decades to come. However, scientific and technological innovations should be introduced for the sustainable use of the conventional energy sources. South Africa is rich in coal reserves and the dependency of the country on fossil fuels is still high. In order to use these conventional sources in a more sustainable way, carbon dioxide emissions generated by them should be reduced, especially generated by the coal-fired power plants (Figure 2.6.4).

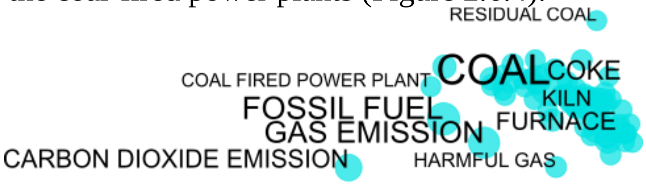


Figure 2.6.4. "Conventional energy sources"

Meanwhile, rich potentials of South Africa on clean and renewable energy sources also need to be exploited. Particularly, the potentials for solar energy are high in the country. There is a need to develop a more holistic and integrated approach for renewables in South Africa, including, the technologies for providing clean and renewable energy sources; solutions for urban and rural areas, such as smart grids in cities and micro energy generation in rural and remote areas; setting up energy storage systems; as well as building necessary technological and skills capacity in the country along with green jobs (Figure 2.6.5).

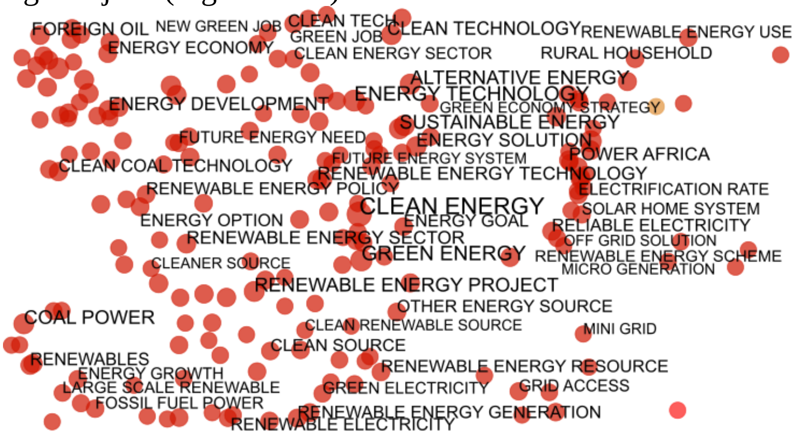


Figure 2.6.5. "Clean and renewable energy"

Besides solar energy, South Africa also has great potentials on Bioenergy. Energy and fuel production from biomass, bioethanol and algae appear to be promising areas for development. A modern biofuel industry with sustainable production principles can be among the main suppliers of the transport fuel in the country (Figure 2.6.6).

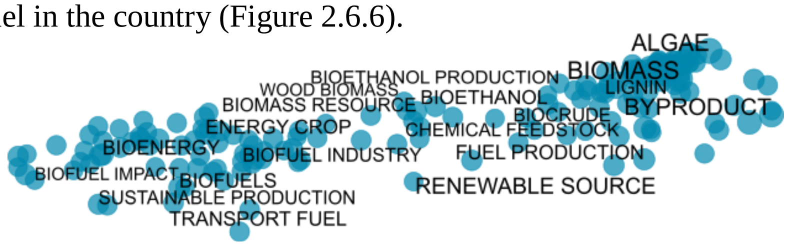


Figure 2.6.6. "Bioenergy"

Providing clean, affordable and sustainable energy for all requires efficient energy policies. Green principles should be at the backbone for the energy policy with an overall aim of providing low cost and low carbon footprint energy for all in the county. Necessary political will should be in place in order to make sure that long term commitment for climate change mitigation, carbon neutrality and social equity targets can be achieved (Figure 2.6.7).

Figure 2.6.7. "Energy policy"

Within energy policy, carbon emissions policy appears to have a special emphasis. Reduction of emissions from fossil fuels is the main global, regional and national priority. There are climate targets and commitments agreed in Kyoto protocol and in other international agreements. There is always a question on how to fund carbon reduction efforts. Carbon regulations and taxation schemes have been implemented to reduce emissions and generate income for scientific and technological innovations to meet emission targets. There is a need for widespread implementation of policy measures at all levels of governance from macro to micro levels – e.g. individual carbon credit/taxation systems (Figure 2.6.8).

Figure 2.6.8. "Carbon emissions policy"

While innovating for new and renewable energy sources, and reducing carbon emission levels, there are expectations by the society for affordable energy. Costs and tariffs need to be balanced to make sure that society, particularly the marginalized, has access to sustainable energy supply. Among alternative ways of energy generation, household solar panel appears to be a technological solution. However, at present this has a limited use. Necessary solutions should be developed for balancing energy demand and supply, tariffs and services (Figure 2.6.9).

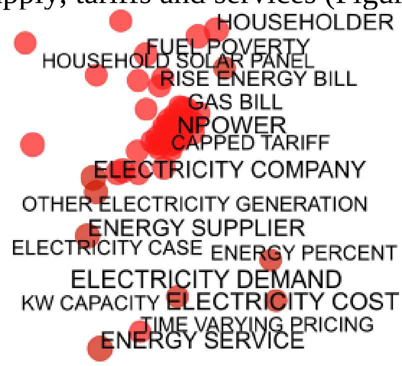


Figure 2.6.9. "Energy costs and tariffs"

EN2: Renewable Energy sources and technologies

Regarding renewable energy sources and technologies, the analysis revealed that solar and wind energy should be high on the agenda in South Africa. As mentioned earlier, the country has considerable potentials for solar energy. This solution is particularly useful for the marginalized to meet their energy demand at an affordable price. Similarly, large-scale solar farms have been implemented in a number of countries for generating large amounts of energy. Widespread implementation of solar energy solutions requires overcoming several technological and technical challenges such as solar energy collection, conversion and combination (Figure 2.6.10).

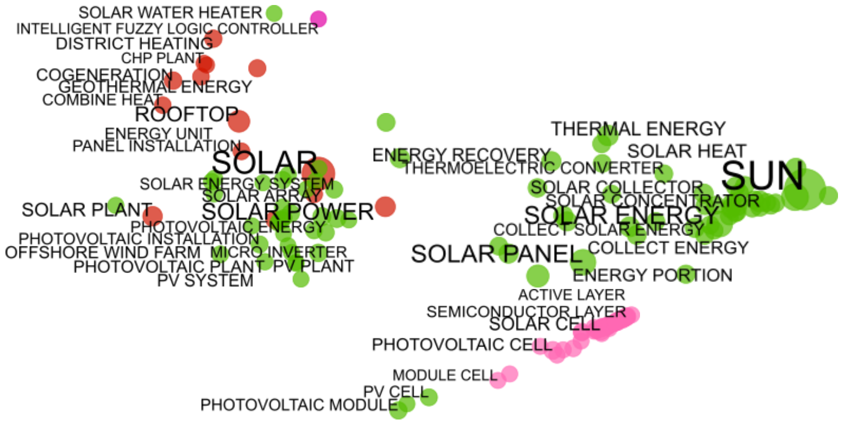


Figure 2.6.10 "Solar energy"

Besides solar energy, South Africa has considerable potentials for wind energy. Issues around the wind energy include the installation of wind turbines and setting up wind farms both on the land and offshore (Figure 2.6.11).

Figure 2.6.11. "Wind energy"

EN3: Energy efficiency solutions for industry plus household use

In addition to energy generation concerns, the consumption aspect should also be at the forefront. Energy costs and expenses can be reduced through the energy efficiency solutions both at the industrial and household levels. Heating and cooling systems should be efficient with lesser demand. Besides devices, building design and technologies should be developed for reduced energy consumption and energy waste (Figure 2.6.12).

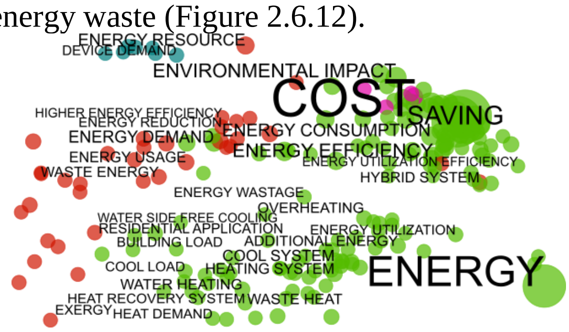


Figure 2.6.12. "Energy efficiency"

Recent years have seen advancements in developing smart energy systems with greater power generation efficiency, better energy capture, and lesser grid loss. Besides smart energy, smart transport systems should have a higher priority on the South African development agenda (Figure 2.6.13).

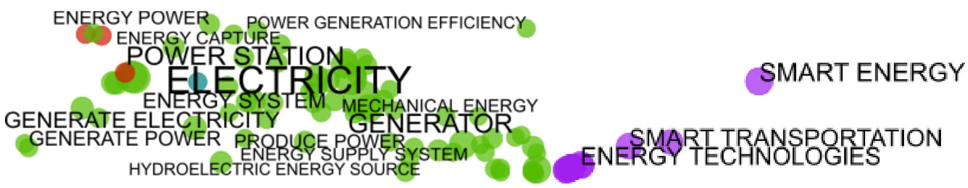


Figure 2.6.13. "Energy system"

EN4: Distributed energy generation and storage

Generating energy near the points of consumption is crucial for achieving greater efficiencies, lesser loses and reduced costs, particularly for the marginalized, who live in far and remote areas of the country. Energy generation, transfer and storage are among the areas for innovation in distributed energy. Furthermore, any use of advanced energy technologies will require setting up smart technologies like smart grids and metering systems (Figure 2.6.14).

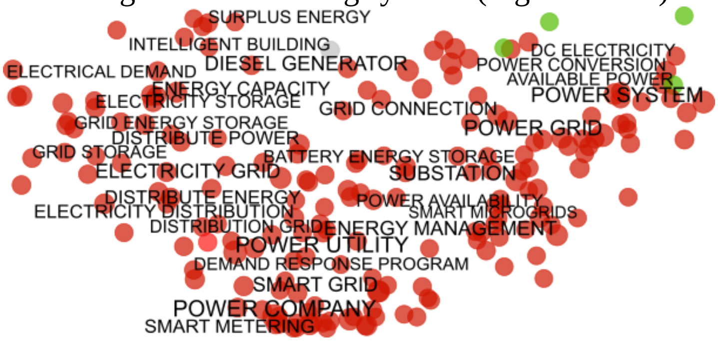


Figure 2.6.14. "Distributed energy generation"

Figure 2.6.15 elaborates the issues around grid energy generation for aforementioned high technology and renewable energy systems. Transition into new energy systems may require an initial investment, however, in the medium to long term they will pay off with cheaper, cleaner and more sustainable solutions.

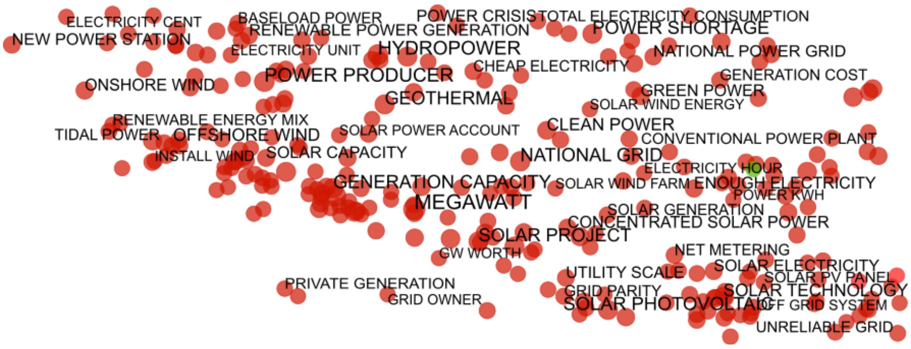


Figure 2.6.15. "Grid energy generation"

Dynamics of “Energy” domain thrusts

In this section, the dynamics of the “Energy” domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts EN3 (Energy efficiency solutions for industry plus household use) appears to be the highest on the agenda (Figure 2.6.16).

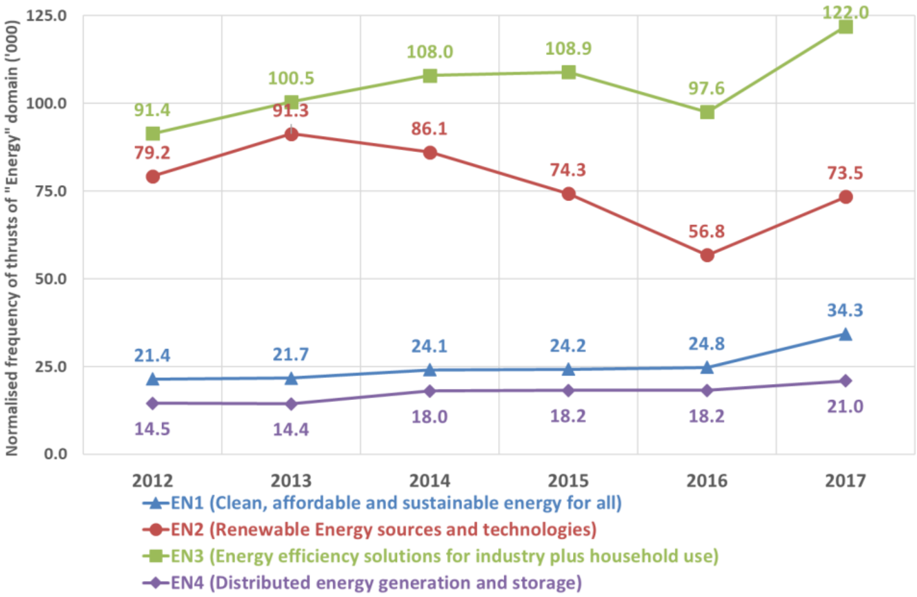


Figure 2.6.16. Normalized frequency of all terms related with thrusts of “Sustainable Energy Technologies for the Marginalized” (Energy) domain ('000) in 2012 – 2017

Note: “Normalized frequency” for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Table 2.6.4 illustrates to what extent the “Energy” domain thrusts address the challenges. Naturally, most of the thrusts in this domain are strongly linked to affordable energy (EN1, EN2 and EN3). EN4 appears to be highly linked with job creation. EN1 is also addressing the carbon emission reduction challenge.

Table 2.6.4. Impacts of all thrusts of “Energy” domain on challenges

Challenges	Energy			
	EN1	EN2	EN3	EN4
Affordable Education	0.0	0.0	0.0	0.0
Affordable Energy	553.7	103.8	117.0	3.0
Affordable Food	4.0	2.0	0.0	1.0
Carbon Emission Reduction	94.0	17.0	3.0	2.0
Clean Water Access	1.0	0.0	0.0	0.0
Crime Prevention	1.0	4.5	11.0	0.0
Crime Reduction	0.0	0.0	0.0	1.0
Economy Growth	5.0	1.0	0.0	1.0
Employment Growth	25.0	3.8	2.0	1.0
Export Growth	4.0	3.5	0.0	1.0
High Living Standard	1.0	2.0	0.0	3.0
High Quality Health Care Service	0.0	0.0	0.0	0.0
Income Growth	6.0	16.3	19.0	1.0
Job Creation	49.0	36.0	5.0	50.5
Low Greenhouse Gas Emission	12.3	35.0	64.0	1.0
Low Mortality	0.0	1.0	0.0	0.0
Population Growth	129.0	22.4	1.0	4.7
Poverty Alleviation	9.0	5.5	0.0	4.0
Reduce Water Demand	1.0	3.0	4.0	0.0
Renewable Energy Growth	44.0	7.3	0.0	0.0
Rural Community	10.5	22.3	2.0	26.0
Secure Water Supply	1.0	1.0	4.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalised number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust EN1) and a specific challenge (e.g. “Low Mortality”) in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge. 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

2.7. EDUCATION FOR THE FUTURE (EDUCATION) DOMAIN

Overall description of the domain

Education is a foundation of a fair society and successful economy. Towards the 2030s, South Africa wishes to provide all its citizens with quality education as a human right. Currently the public education system suffers from the problems of effectiveness of mathematics and science. Citizens of the country, particularly in rural areas, have expectations for accessing quality learning opportunities. Technology provides an ever-growing range of opportunities to provide this access. New and alternative learning technologies will not only give people basic education, but will also equip them with necessary skills for the future, while reducing divides in the society. Besides implementing new technologies, curriculum should also be developed in line to enable people to be more creative with skills for idea generation and problem solving.

Overview of research potential of South Africa in "Education" domain

Figure 2.7.1 shows that there is a growing scientific emphasis on the "Education" domain in South Africa. Although the number of publications is relatively low compared to other STI domains, some growth has been observed, particularly in year 2014. In recent years, share of South Africa's contribution to total scientific pool has accessed 1.22% with the high of 1.44% in 2014.

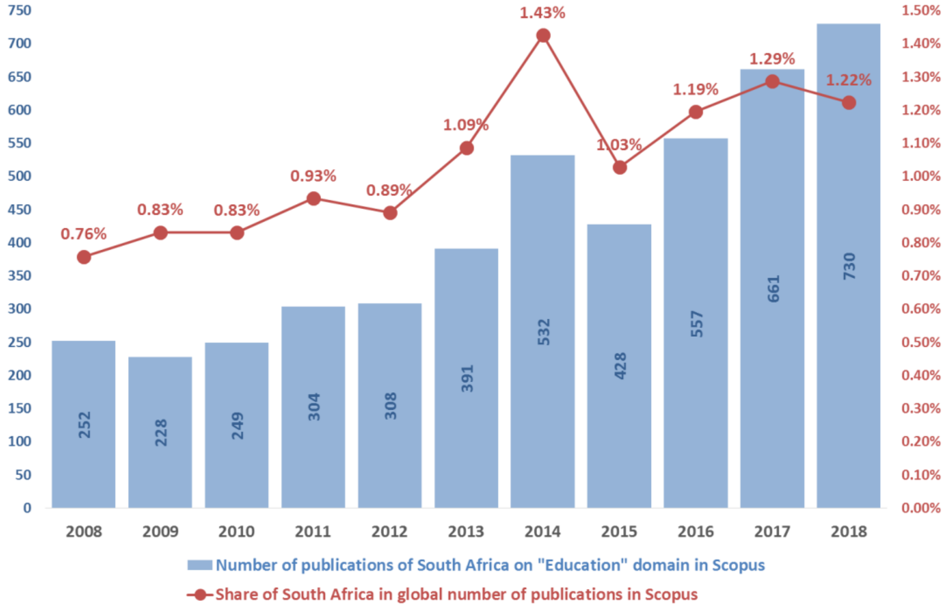


Figure 2.7.1. Dynamics of publications of South Africa in "Education" domain in Scopus in 2008 – 2018

Note: all types of documents except of technical documents, indexed in Scopus are included in the analysis.

Figure 2.7.2 shows the leading countries in the Education domain. Compared to other domains South Africa is positioned high in this domain with the 16th place.

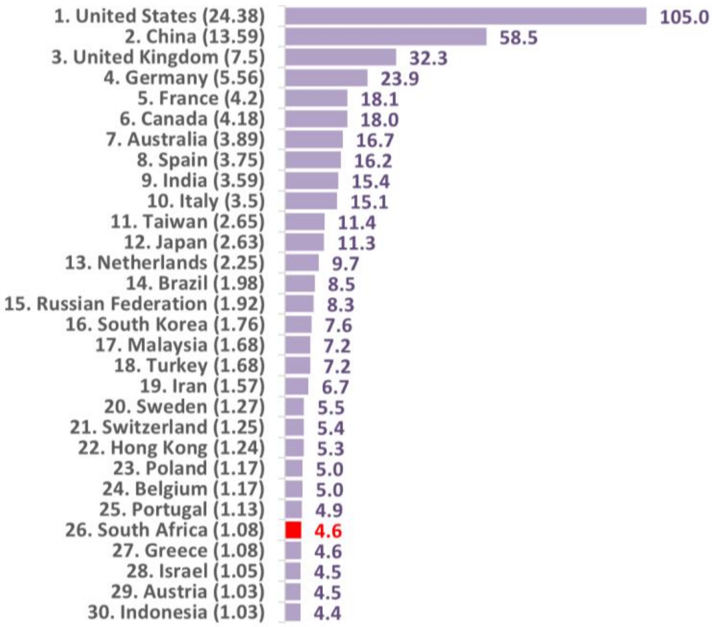


Figure 2.7.2. Leading countries by number of publications ('000) on "Education" domain in Scopus for 2008 – 2018

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Share of a country in global number of publications is shown in parenthesis.

Among the key partner countries of South Africa are the United States, the United Kingdom, Germany, Australia and Canada. Nigeria comes as the first African collaborator with the 9th place among the top collaborators (Table 2.7.1).

Table 2.7.1. Key partner countries of South Africa in internationally collaborated publications in "Education" domain in Scopus for 2008 - 2018

Country	Number of Joint papers with South Africa	Share of a country in all ICPs of South Africa
United States	300	21.60%
United Kingdom	265	19.08%
Germany	122	8.78%
Australia	111	7.99%
Canada	108	7.78%
Netherlands	84	6.05%
China	81	5.83%
Sweden	63	4.54%
Nigeria	56	4.03%
India	55	3.96%
France	53	3.82%
Belgium	51	3.67%
Zimbabwe	48	3.46%
Italy	40	2.88%
Spain	38	2.74%
Switzerland	38	2.74%
Greece	34	2.45%
Russian Federation	32	2.30%
South Korea	31	2.23%
Finland	30	2.16%
Norway	30	2.16%
Pakistan	29	2.09%
Ghana	24	1.73%
Austria	23	1.66%
Botswana	22	1.58%

Kenya	22	1.58%
Denmark	21	1.51%
Turkey	21	1.51%
Brazil	20	1.44%
Czech Republic	20	1.44%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis.

Table 2.7.2 shows the leading organizations in South Africa publishing in the domain of Education with the total number of publications they produced in the last 10 years, as well as the percentage of their contribution in the total scientific output.

Table 2.7.2. Leading organizations of South Africa by number of publications in "Education" domain in Scopus for 2008 – 2018

Affiliation	Number of publications	Share in all South Africa publications
University of South Africa	536	11.55%
Universiteit van Pretoria	518	11.16%
University of Witwatersrand	463	9.98%
University of Cape Town	455	9.81%
University of KwaZulu-Natal	418	9.01%
University of Johannesburg	387	8.34%
North-West University	358	7.72%
Universiteit Stellenbosch	327	7.05%
University of the Free State	195	4.20%
University of the Western Cape	170	3.66%
Tshwane University of Technology	139	3.00%
Cape Peninsula University of Technology	125	2.69%
Rhodes University	117	2.52%
The Council for Scientific and Industrial Research	89	1.92%
Nelson Mandela Metropolitan University	83	1.79%
South African Medical Research Council	65	1.40%
Durban University of Technology	64	1.38%
Central University of Technology, Free State	64	1.38%
University of Fort Hare	56	1.21%
University of Limpopo	55	1.19%
Human Sciences Research Council of South Africa	54	1.16%
Meraka Institute	47	1.01%
Vaal University of Technology	39	0.84%
Walter Sisulu University	38	0.82%
University of Zululand	37	0.80%
University of Venda for Science and Technology	37	0.80%
Mangosuthu University of Technology	15	0.32%
University of Cape Town, Faculty of Health Sciences	11	0.24%
The Nelson R. Mandela Medical School	10	0.22%

Note: 1. All types of documents except of technical documents, indexed in Scopus are included in the analysis. 2. Organization names are presented as they are spelled in Scopus database.

Semantic analysis of "Education" domain

This section describes the "Education for the Future" domain and analysis of its thrusts based on the results produced by the iFORA system. First, the full domain is described with a domain map including all of the topics covered. Then each of the thrusts is described by the emerging topics identified by iFORA. The next section presents topic clusters under each thrust with more detailed network maps with descriptions of emerging issues under them. Figure 2.7.3 shows the entire domain of "Education for the Future (ED)" with its clusters and interrelations to each other. A detailed analysis of Figure 1 provides an overview of ED thrusts and a number of existing emerging topics for consideration under each of them. These are presented in Table 2.7.3. In the following section network maps are given to illustrate these maps and further issues emerging under each of them.

Table 2.7.3. "Education for the Future" thrusts and topics

ED Thrusts	Topics emerging under each thrust
ED1: Skills for the 4th Industrial Revolution	"Technology development" and "Digitalization (Fig. 2.7.4)
	"Innovation and entrepreneurship" and "Creativity, problem solving and idea generation" (Fig. 2.7.5)
ED2: Inclusive innovation & development	"Inclusive development" and "Employment and job search" (Fig. 2.7.6)
	"Student career development" and "preschool learning" (Fig. 2.7.7)
ED3: Curriculum development 2030	"Curriculum development" (Fig. 2.7.8)
	"Skill development" and "Basic skills" (Fig. 2.7.9)
	"Primary and secondary school" (Fig. 2.7.10)
	"Higher education system" (Fig. 2.7.11)
	"Engineering education" (Fig. 2.7.12)
	"Online education" (Fig. 2.7.13)
	"Education policy" (Fig. 2.7.14)

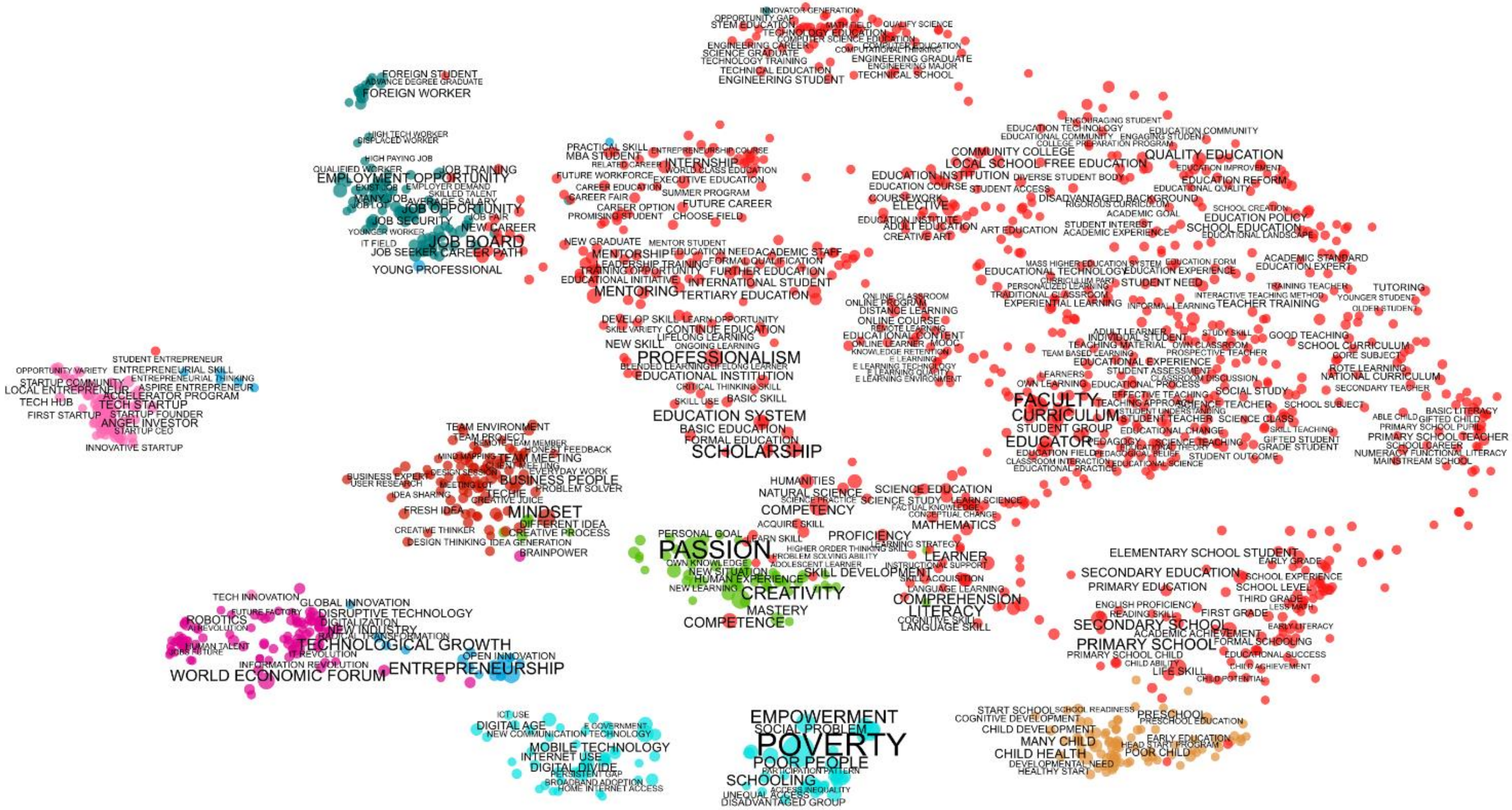


Figure 2.7.3. "Education for the Future" domain full semantic map for 2014-2018

“Education for the Future” Thrusts
ED1: Skills for the 4th Industrial Revolution

Innovations and transformations always require new skills and capabilities. The 4th Industrial Revolution is not an exception. Two of the main drivers of the 4th Industrial Revolution are technology development and digitalization. There are a number of technologies, which are likely to bring disruptions. Among them are robotics, Artificial Intelligence and new methods for production. The digitalization trend itself transforms economy, energy, health, communication and all other industries. In the age of digitalization, it is important for society to be a part of the process. At the very basic level most of the students, if not all, need to have Internet access with higher broadband adoption rates. Failing in providing Internet access to the society and marginalized may increase the digital divide in society (Figure 2.7.4).

Figure 2.7.4. “Technology development” (left) and “Digitalization (right)

New technological developments and new jobs to be created will require development of new skills and capabilities. These include innovation and entrepreneurship skills. Particularly innovative start-ups are likely to make social, economic and technological contributions, while generating highly qualified and skilled employment. In order to start such initiatives, it is important to create a culture of entrepreneurial thinking, skills and programs for supporting young entrepreneurs. Furthermore, new industrial revolution will also require skills like creativity, problem solving and idea generation, which are the keys for innovation. Design thinking, teamwork, and critical thinking appear to be other important skills, which will make a difference for humans in the age of smart technologies and machines (Figure 2.7.5).

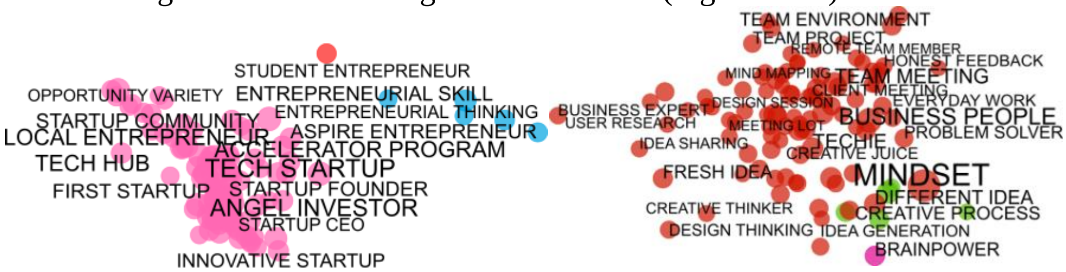


Figure 2.7.5. “Innovation and entrepreneurship” (left) and “Creativity, problem solving and idea generation” (right)

ED2: Inclusive innovation & development

Inclusive innovation and development require empowerment of poor people and disadvantaged groups into the process of innovation. Education and schooling are certainly the first steps in generating awareness and achieving greater inclusivity. Education should be supported with a continuous empowerment through the generation of new and highly qualified jobs for younger people. Regular and higher income jobs with clear career paths will help to create a healthier society with a more sustainable economic system and greater possibilities for the marginalized (Figure 2.7.6).

Figure 2.7.6. "Inclusive development" (left) and "Employment and job search" (right)

Career development should be started from the earlier levels of education even starting at the preschool level. At the school level students should be provided necessary mentorship and guidance. Future career options should be shown to them. Promising students should be directed towards future careers where they may indicate higher potentials in tertiary and higher education. The process can actually begin at the preschool stage. Child development, readiness for school, and cognitive development are among the most important factors for a healthy start to school and future careers. Poor children also need to be considered at this stage for their successful integration into inclusive innovation and development processes (Figure 2.7.7.).

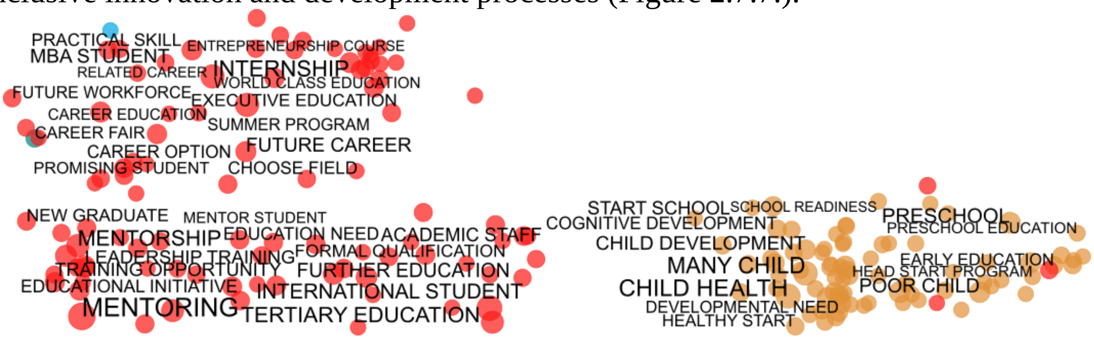


Figure 2.7.7. "Student career development" (left) and "preschool learning" (right)

ED3: Curriculum development 2030

Continuous curriculum development is a must for the education system to prepare students for the future. This holds true for all levels of education from pre-/primary school to higher education. New curriculum to be developed should allow up-to-date teaching materials and effective teaching methods, and should allow an interactive process with students actively involved in classroom discussions and working in teams where possible. Good teaching practices should be developed and should be made widespread across schools. Continuous education of educators is also a must for adapting teachers into new teaching methods with relevant teaching materials (Figure 2.7.8).

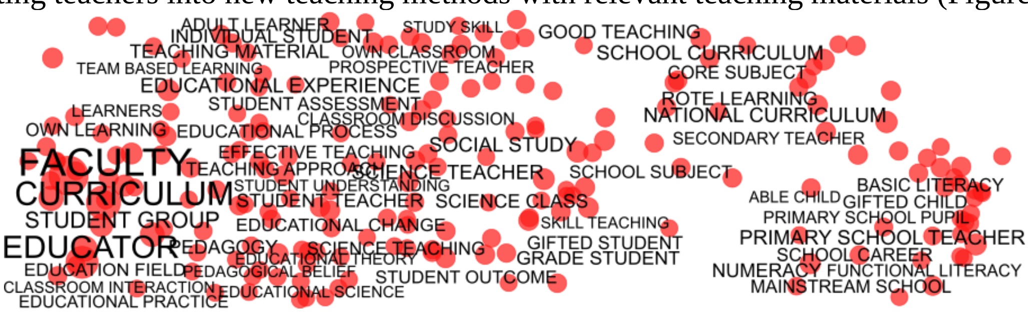


Figure 2.7.8. "Curriculum development"

Curriculum development should help to develop skills for the new industrial developments discussed earlier. As mentioned earlier, new curriculum to be developed should contribute to cognitive and critical thinking skills, as well as creativity and problem solving abilities. For sure, the knowledge society enabled by new technologies require a solid science education, mathematics and language learning as basic skills (Figure 2.7.9).

Figure 2.7.9. “Skill development” (left) and “Basic skills” (right)

Starting from the primary school, reading and language seem to be important skills to be gained. Understanding children’s potentials from the early ages is important for future educational success (Figure 2.7.10).

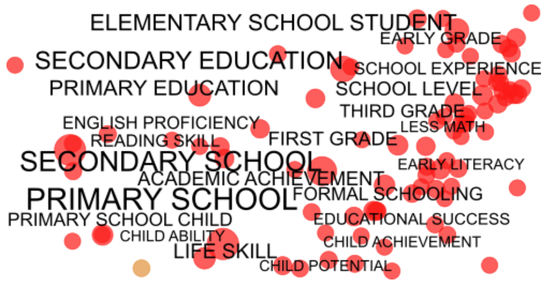


Figure 2.7.10 “Primary and secondary school”

Similarly, at the level of higher education, it is important to increase academic and educational standards. Newest educational technologies should be exploited to enable experiential and personalized learning with interactive teaching methods (Figure 2.7.11).

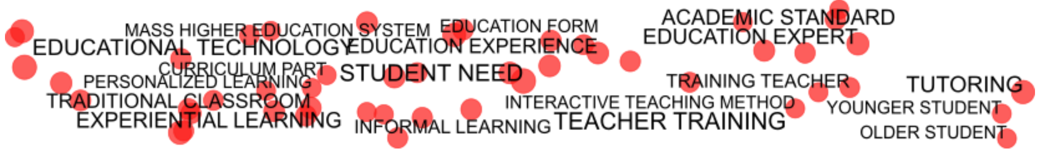


Figure 2.7.11. “Higher education system”

In relation the new industrial revolution and curriculum development to address the emerging scientific and technological needs, an overhaul in the engineering education is crucial. Science, computer, mathematics and technical education will remain at the core of the engineering curriculum (Figure 2.7.12).

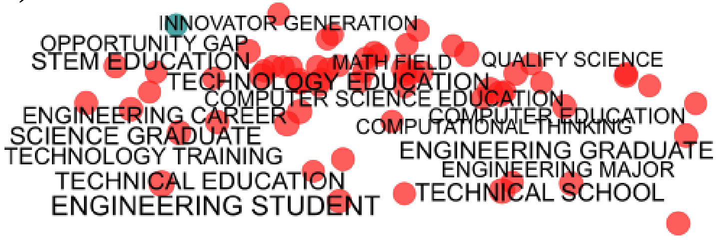


Figure 2.7.12. “Engineering education”

The increasing use of Information and Communication Technologies will also have implications on the way education is delivered. There is an increasing trend for delivering courses online. This will enable possibilities for distant learning, which would also help the marginalized and remote layers of the society to access the education systems. For instance, MOOC courses enable accessing online courses not at the national level, but also at the global level from all centers of excellence in the world. Necessary e-learning technologies, infrastructure and ecosystem need to be set up to enable online education (Figure 2.7.13).

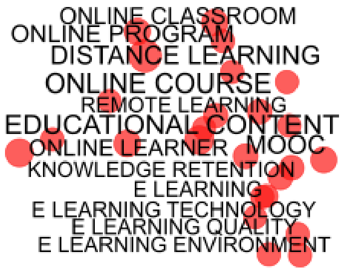


Figure 2.7.13. "Online education"

In order to implement the aforementioned transformations in the education system, there is a need for efficient education policies. There are a wide variety of issues to be addressed. Overall, the quality of the education should be increased at all levels. Particularly for the marginalized and disadvantaged parts of the society education should be delivered for free or at least at minimal costs for increased access. Besides student education, adult education should also be given emphasis so that there will not be educational, social or technological divides in the society. Scientific and technical skills are important, however, necessary education for creativity and arts should also be delivered in a balanced way. Community colleges and local schools should be empowered (Figure 2.7.14).

Figure 2.7.14. "Education policy"

Dynamics of "Education" domain thrusts

In this section, the dynamics of the "Education" domain thrusts are shown based on their frequency of occurrence in the documents indexed in the iFORA database. Among the thrusts ED1 (Skills for the 4th Industrial Revolution) and ED3 (Curriculum development 2030) appear to be the highest on the agenda. ED2 remains largely insignificant (Figure 2.7.15).

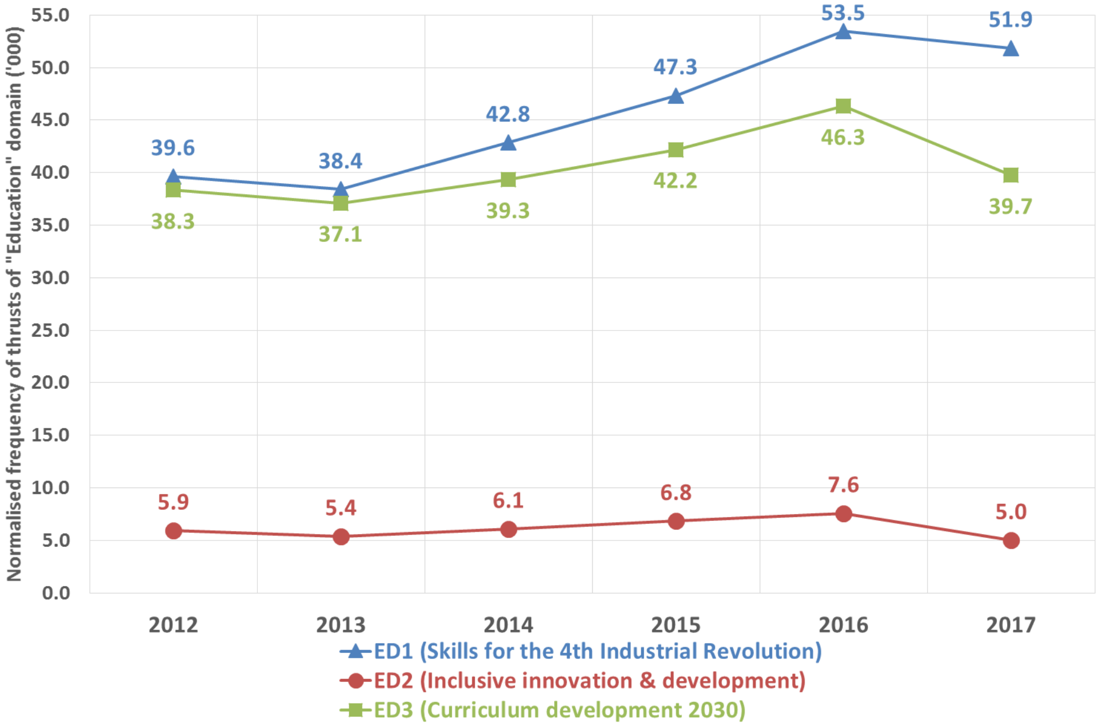


Figure 2.7.15. Normalized frequency of all terms related with thrusts of "Education" domain ('000) in 2012 – 2017

Note: "Normalized frequency" for a specific thrust is a total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with this specific thrust in documents indexed in IFORA for a given year.

Furthermore, Table 2.7.4 illustrates to what extent the “Education” domain thrusts address the challenges. Education thrusts are linked to job creation and employment growth with contributions in addressing rural community, population growth and skill improvement.

Table 2.7.4. Impacts of all thrusts of “Education” domain on challenges

Challenges	Education		
	ED1	ED2	ED3
Affordable Education	0.0	0.0	14.0
Affordable Energy	0.0	0.0	3.3
Affordable Food	0.0	0.0	0.0
Carbon Emission Reduction	1.5	0.0	0.0
Clean Water Access	0.0	0.0	0.0
Crime Prevention	1.0	0.0	4.0
Crime Reduction	1.0	0.0	1.0
Economy Growth	0.0	0.0	0.0
Employment Growth	6.0	2.0	2.5
Export Growth	3.0	0.0	2.0
High Living Standard	1.0	0.0	9.0
High Quality Health Care Service	0.0	0.0	0.0
Income Growth	0.0	0.0	9.5
Job Creation	7.0	1.0	71.3
Low Greenhouse Gas Emission	0.0	0.0	1.0
Low Mortality	0.0	0.0	0.0
Population Growth	4.3	0.0	3.3
Poverty Alleviation	1.0	0.0	6.0
Reduce Water Demand	0.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	0.0
Rural Community	3.7	0.0	32.0
Secure Water Supply	0.0	0.0	0.0
Skill Improvement	3.5	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0

Notes: 1. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (that are shown on a semantic map) related with a specific thrust (e.g. Thrust ED1) and a specific challenge (e.g. “Low Mortality”) in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact.

3. CONCLUSIONS

Development of internationally competitive science and technology is able to contribute to the creation of national wealth and societal progress is among the key prerequisite of success for any big nation including South Africa. Selection of promising fields of research and relevant areas of practical applications of scientific findings is one of major issues for national science and technology policy. The "South Africa Science, Technology and Innovation (STI) Foresight for 2030" identifies seven STI domains and related priorities (thrusts) to be addressed by national innovation strategies in the decade to come.

The review of current state and prospects of national capacities in these domains and thrusts presented in the report is based on a comprehensive semantic analysis of big data as well as on the analysis of publication activities. The country's research landscape, its strengths and weaknesses, benchmark vis-à-vis global leaders and leading research institutions, scientific specializations and international partners: one can find a lot of detailed information on all this issues in the report. A big number of visual presentations, graphs and tables provide a broad picture of the national science and technology capacities and, on the other hand, show key economic and societal problems to be resolved with the use of these capacities.

New technologies have to serve needs of society and society is changed by new technologies. The analysis of STI domains and thrusts shows how important is co-evolutionary development of science and technology and society. Comparing the scientific output with the priority STI domains and thrusts, the present report indicate that in some areas of STI, such as ICTs, South Africa's position is research is relatively low, despite the fact that almost all seven STI domains are closely linked to the development of ICTs. In this way, the report shows somewhat the feasibility of the STI goals and targets. Strategies need to be developed to implement a balanced development of research, capacities, skills and infrastructures.

Being one of the first examples of using big data for setting STI priorities, the present report can also help to derive new ideas for researchers, setting agendas and promoting systematic planning among policy-makers and better use of new technologies by industries, it might also help all of them and ordinary citizens to be better prepared for the future.

ANNEX: METHODOLOGICAL NOTES

We built the present study on the "Intelligent Foresight Analytics System" (iFORA), which was developed by the National Research University Higher School of Economics (HSE). The documents fed into the system were collected from open data sources: scientific articles from CrossRef database[5], United States Patent and Trademark Office (USPTO) patents[6], National Science Foundation (NSF) grant awards[7], news feed and media publications of influential media and sectoral organizations (e.g. MIT Technology Review, CNN), analytical reports of international organizations (e.g. Food and Agriculture Organization of United Nations, FAO). Metadata, such as titles, publication dates, lists of authors, organizations, were processed by the PostgreSQL[8] database for further statistical analysis.

Figure 4.1 describes iFORA's main data sources, architecture and main technologies applied:

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[5] https://www.crossref.org/
[6] https://www.uspto.gov/
[7] https://www.nsf.gov/awardsearch/
[8] https://www.postgresql.org/

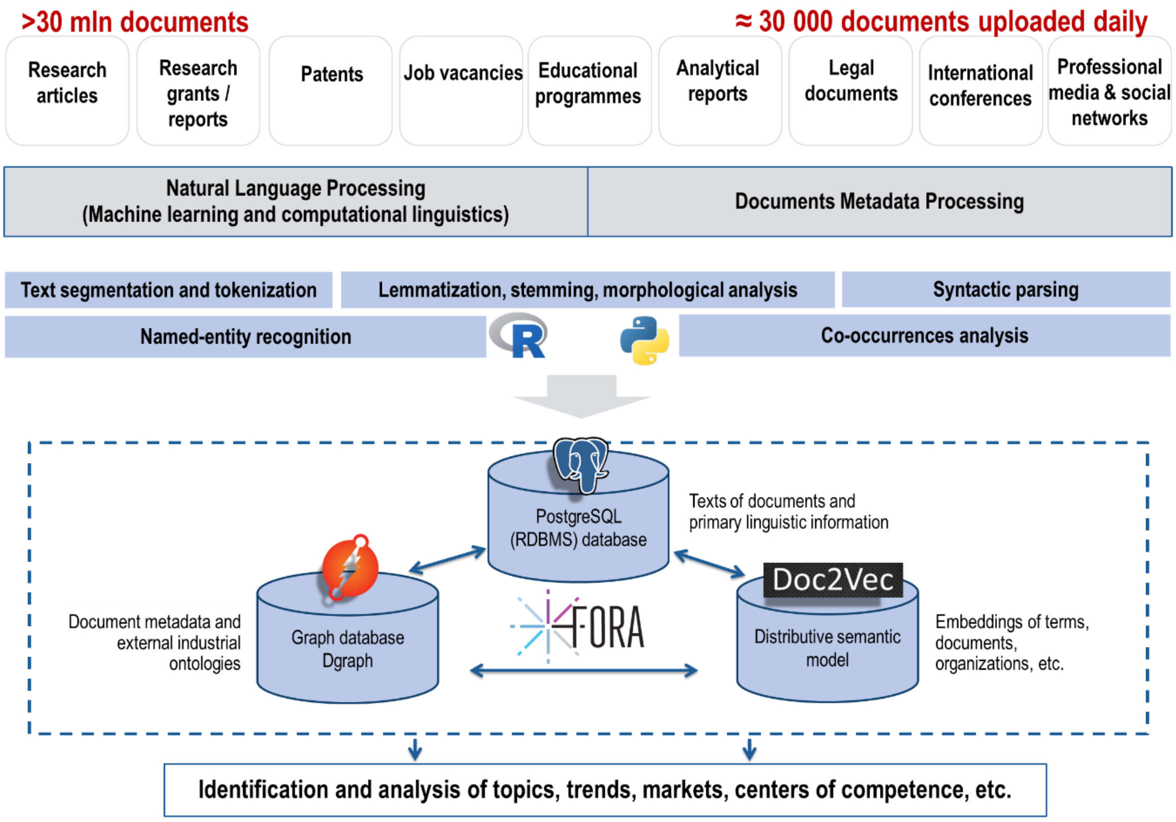
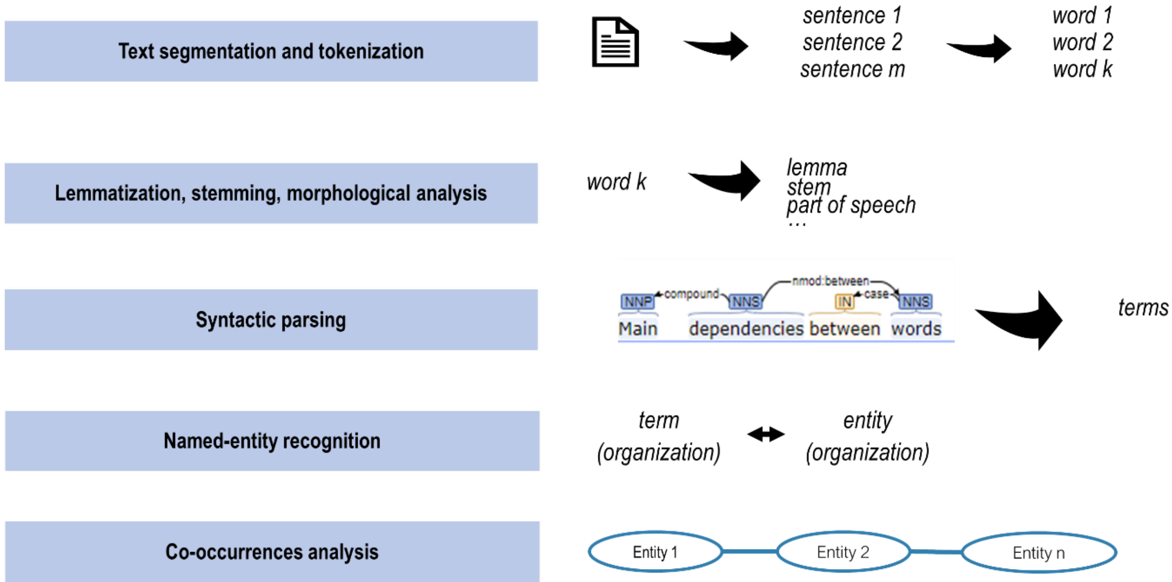


Figure 4.1. iFORA: sources, architecture and technologies

The analysed texts (including titles, abstracts, patent claims, etc.) were split into separate sentences, words, lemmas and stems with all morphological characteristics for natural language processing with Python's open software package Spacy[9]. Syntactic analysis of dependencies between words, particularly adjective modifiers and compounds of Universal Dependencies[10], helped to identify key phrases for each sentence. Figure 4.2 shows schematically how the process was done:



[9] https://spacy.io/
[10] http://universaldependencies.org/u/dep/index.html

Figure 4.2. iFORA's NLP pipeline

The system follows best practices of words' semantic meaning identification (Mikolov, et al., 2013; Pennington, et al., 2014; Bojanowski, et al., 2017) to strengthen natural language processing with word embeddings. These word embeddings build numeric n-dimensional vector representation in the same vector space for each term in iFORA's 30 million documents. The distributed semantic skip-gram model was trained using neural network technology called word2vec/doc2vec as part of the Python package gensim[11]. The model used 200 parameters for building vector spaces with a minimal occurrence of 5 terms, window size of 6 terms and hierarchical SoftMax optimization of neural network hidden layer weights for each term. Figure 4.3 demonstrates the process of training iFORA's distributed semantic model:

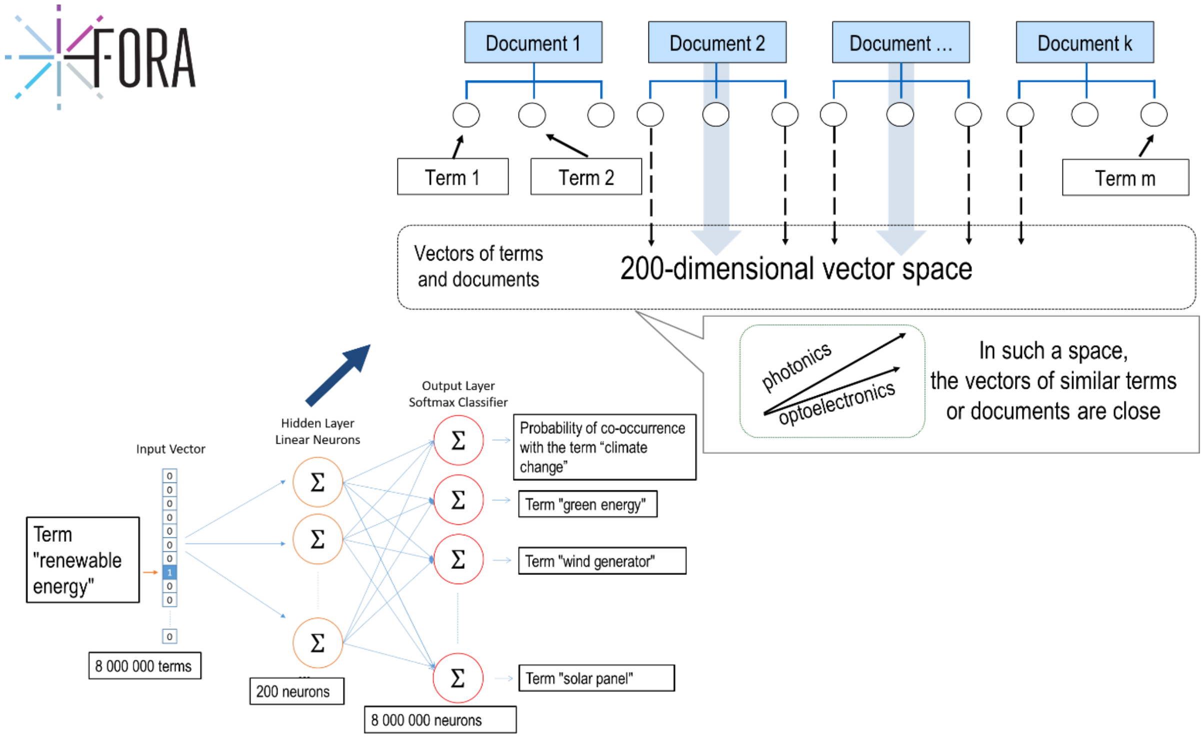


Figure 4.3. Training of iFORA's distributed semantic model

The initial keywords were extracted from domain and thrust descriptions made by South African experts.

The system searched for all related terms in thematic proximity. For each keyword, the top-100 terms with the cosine similarity not less than 0.6 were identified. The metric of similarity in the 200-dimensional vector space is further described by following formula (1):

$$CosSim_{A,B} = \frac{\sum_{i=1}^{n=200}(A_i * B_i)}{\sqrt{\sum_{i=1}^{n=200}(A_i^{\,2})} * \sqrt{\sum_{i=1}^{n=200}(B_i^{\,2})}} \quad (1)$$

A, B – two terms being compared,
A_i – i^{th} value of the term A in 200-dimensional vector representation,
B_i – i^{th} value of the term B in 200-dimensional vector representation.

[11] https://radimrehurek.com/gensim/models/word2vec.html

The clustering of terms for each domain into groups (or, in semantic meaning *topics*) was based on the following algorithm:

1. *principal component analysis (PCA)* reduced the dimensionality of terms from 200 dimensions to 50 based on Python's open software package sklearn.decomposition[12];
2. *t-distributed stochastic neighbor embedding (t-sne)* calculated coordinates of each term in 2-dimensional space from 50 pca parameters using Python's open software package sklearn.manifold[13];
3. the clustering of terms based on *average cosine similarity hierarchical clustering*.

Further to expand the corpus of keywords that are searched within iFORA framework the tool multiplier of scientific and technical search terms that provides a deep search for specific information and minimizes the work of analysts on the selection of the relevant keywords. Figure 4.4 shows the result of application of multiplier of scientific and technical terms for the search queries "aviation" and "aircraft". They analysis of this figure shows how multiplier of scientific and technical terms works. The initial search query, containing two terms "aviation" and "aircraft", were expanded ("multiplied") to 500 terms in databases of professional media information sources (proxy for markets), to 400 terms in databases of scientific publications (proxy for science) and to over 600 terms in patent databases (proxy for technology). The words that are most commonly associated with given search terms are more prominently highlighted. Such an analysis is carried out is much faster than a similar work of a general analyst on reaching and selection of the relevant terms that are related with "aviation" and "aircraft".

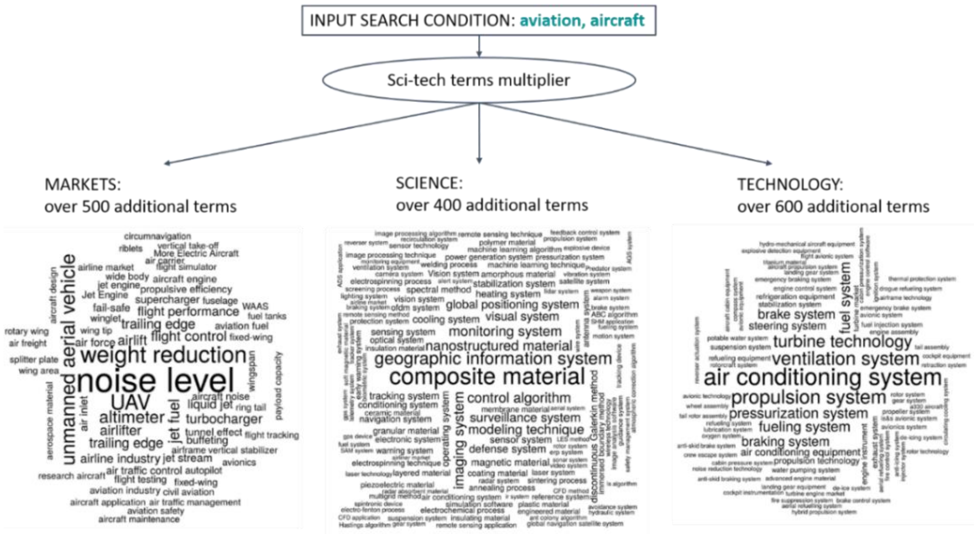


Figure 4.4. Multiplier of scientific and technical terms in global aircraft industry
Source: HSE ISSEK iFORA.

Table 4.1 presents as example the list of keywords related with four thrusts of (Nutrition) domain.

Table 4.1. Initial List of keywords related with thrusts of "Nutrition Security for a Healthy Population" (Nutrition) domain that were uploaded to multiplier of scientific and technical search terms

Thrusts of "Nutrition" domain	Terms uploaded to multiplier of scientific and technical search terms

[12] http://scikit-learn.org/stable/modules/generated/sklearn.decomposition.PCA.html
[13] http://scikit-learn.org/stable/modules/generated/sklearn.manifold.TSNE.html

NU1 (Zero Impact Agriculture)	aquaponic; aquaponics; desalination; drought tolerance; food basket; food security; healthy meal; local agriculture; nutritional improvement; smallholder farmer; small-scale farming; sustainable agriculture; sustainable food production; water quality enhancement; water scarcity
NU2 (Use and acceptance of modern biotechnology)	biotech crop; disease resistant crop; food shortage; food waste; genetically modified crop; genetically modified organism; genome edited crop; healthy food; herbicide tolerance; insect resistance; micronutrient deficiency; modern biotechnology; pathogen resistant plant; pest resistant crop; plant biotechnology; plant genetic engineering; plant genomics
NU3 (Personalised information for healthy nutrition for all)	balanced nutrition; fast food; food choice; food insecurity; food labelling; food policy; good food choice; healthy diet; healthy food choice; healthy nutrition; hunger; malnourishment; malnutrition; nutrition information; nutrition outcome; nutrition policy; nutrition security; nutrition status; nutritional status; nutritious food; obesity; poor diet; poor dietary habit; stunting; sugary drink
NU4 (Precision & big data in agri-businesses)	precision agriculture; precision farming

For each South Africa domain a semantic map based on list of initial keywords (that were further extended via) related with thrust was made. This semantic map is segmented on different clusters of keywords related with different thematic topic. On each semantic map colors represent topics and position representing similarity of terms towards each other. Clusters were then manually tagged to display their impact on any of thrusts within the domain. Size of a specific bubble represents impact of this specific term for South Africa (based on co-occurrence of this specific term with the word "South Africa" in documents). Based on the obtained visualizations, we can quickly draw conclusions about which scientific and technical trends related with South Africa thrusts and domains receive the most attention in various information sources. Fragments of semantic map for "Nutrition Security for a Healthy Population" (Nutrition) domain are presented on Figure 4.6.

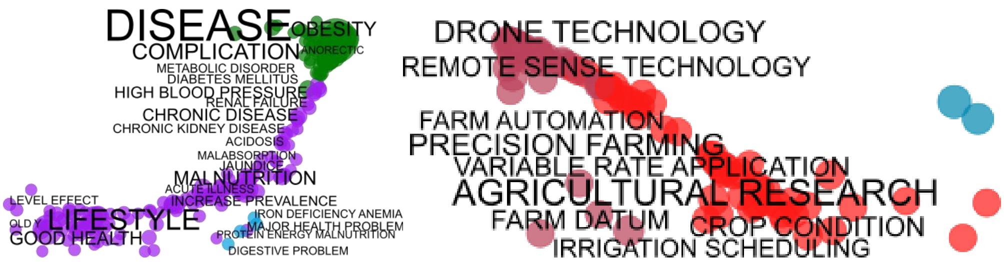


Figure 4.5. "Nutrition diseases" (left) and "Precision agriculture" (right) fragments of semantic map for "Nutrition" domain

Dynamics of thrusts and their impact onto challenges

To identify trends in the dynamic of thrusts we estimated the annual frequency of all terms related with thrusts in iFORA indexed documents collected for each year. Figure 4.6 shows the total normalized number of mentions (in thousands) of all terms (that are shown on a semantic map) related with four thrusts of "Nutrition" domains in documents indexed in IFORA for a given year. Among the thrusts NU3 (Personalized information for healthy nutrition for all) appears to be the highest on the agenda.

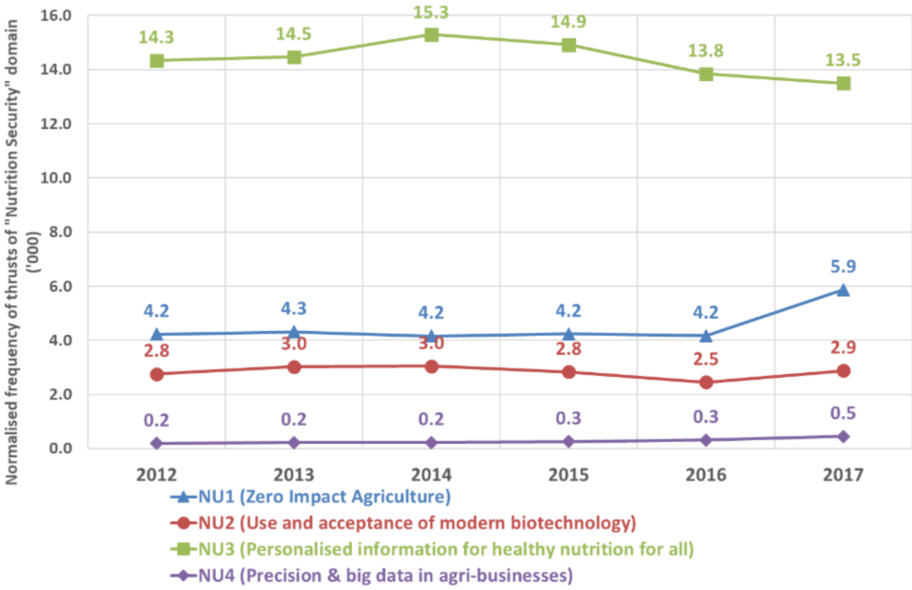


Figure 4.6. Normalized frequency of all terms related with thrusts of "Nutrition" domain ('000) in 2012 – 2017

The impact of thrust onto South Africa challenges was calculated as follows. The 26 terms listed as challenges (see Table 4.2) – are the terms that were extracted from the text describing the domains of South Africa and identified as special tasks and challenges for South Africa development. The impact of thrusts onto challenges was calculated based on co-occurrence of terms related with a specific thrust and terms that are identified as challenges.

Table 4.2. Impacts of all thrusts of "Nutrition" domain on challenges

Challenges	Nutrition Security			
	NU1	NU2	NU3	NU4
Affordable Education	0.0	0.0	1.0	0.0
Affordable Energy	5.5	0.0	4.3	0.0
Affordable Food	2.5	103.0	20.7	0.0
Carbon Emission Reduction	0.0	0.0	1.0	0.0
Clean Water Access	2.5	1.0	1.0	0.0
Crime Prevention	4.0	0.0	5.0	0.0
Crime Reduction	0.0	0.0	1.0	0.0
Economy Growth	0.0	0.0	0.0	0.0
Employment Growth	0.0	0.0	4.5	0.0
Export Growth	0.0	2.0	3.0	0.0
High Living Standard	3.0	3.0	2.0	0.0
High Quality Health Care Service	0.0	0.0	2.0	0.0
Income Growth	14.5	5.0	12.0	2.0
Job Creation	11.3	4.7	9.0	1.0
Low Greenhouse Gas Emission	2.0	2.0	2.7	0.0
Low Mortality	1.0	10.0	49.3	0.0
Population Growth	9.7	18.0	47.0	0.0
Poverty Alleviation	10.0	8.0	13.0	0.0
Reduce Water Demand	8.0	8.0	0.0	0.0
Renewable Energy Growth	0.0	0.0	1.0	0.0
Rural Community	28.0	9.8	21.3	5.0
Secure Water Supply	9.0	0.0	0.0	0.0
Skill Improvement	0.0	0.0	0.0	0.0
Universal Broadband Access	0.0	0.0	0.0	0.0

Table 4.2 provides the measures of the impact of thrusts of "Nutrition" domain onto challenges. Value in each specific cell of this table is a normalized number of co-occurrences of all terms (shown on a semantic map) related with a specific thrust (e.g. thrust NU1) and a specific challenge (e.g. "Low Mortality") in documents indexed in iFORA database for 2012 – 2017. This value is treated as an impact of a specific thrust onto a specific challenge 2. Cells are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact. Cells of table 4.2 are colored by bars as follows: within a column of a specific thrust the biggest green bar means the challenge for which this specific thrust has the highest impact. In the case of thrusts of "Nutrition" domain the highest impact refers to "affordable food", "low mortality"; "population growth" and "rural community" challenges.

Research potential of South Africa in the studied domains

Research potential of South Africa in seven domains was assessed via basic publication activity indicators of South Africa and other countries in Scopus database. Scopus database was founded by publishing corporation Elsevier in 2004. Scopus is one of the two largest international database of scientific publications (the other database in this aspect is web of Science). As of April 2019, 74.5 mln scientific documents (journal articles, reviews, conference papers, books, book chapters etc.) were indexed in Scopus database. Among them almost 356 thousand documents (0.48% of global publication output) – are publications of South Africa –(i.e. publications where at least one author from South Africa[14] is automatically identified).

[14] If a specific author has several affiliations and one of this affiliations is affiliation with South Africa – this author will be identified as author from South Africa.

The time span of our analysis covers the period of 2008- 2018 to take into account the latest trends in publication activity of South Africa. We also restrict the corpus of documents indexed in Scopus by those documents that can be treated as scientific publication[15]: scientific article; scientific article in press; review; conference paper; book, book chapter; letter; note; editorial. Publications related with a specific domain were searched in Scopus via running in titles and/or abstracts and/or keyword lists of publications the query search that contains terms that related with thrusts of a specific domain. Here in Scopus we searched those terms that were search in iFORA database plus some additional terms that were found in the text describing South Africa domains. Terms related with thrusts of "Nutrition" domain that were searched in titles and/or abstracts and/or keyword lists of publications indexed in Scopus are provided in Table 4.3.

Table 4.3. List of terms related with thrusts of "Nutrition Security for a Healthy Population" (Nutrition) that were used in Scopus query search

Thrusts of "Nutrition" domain	Terms included in Scopus query search
NU1 (Zero Impact Agriculture)	aquaponic*; closed irrigation; desalinat*; drought tolera*; fish* farm*; food basket*; food security; healthy meal; local agricultur*; marginal soil*; nutrition* improvement*; saltwater conversion; saltwater evaporation; secure agricultural productivity; small agri-business; smallholder farm*; small-scale farm*; sustainable agriculture*; sustainable food production; urban farm*; water quality enhancement*; water saving; water scarcity
NU2 (Use and acceptance of modern biotechnology)	animal health; biotech* crop*; crops yield; disease resistant animal*; disease resistant crop*; fertiliser*; fertilizer*; food shortage*; food waste*; gen* edited crop*; gene* modif* crop*; gene* modif* organism*; GM crop*; healthy food; herbicide tolera*; insect resist*; micronutri* defici*; modern biotechnology*; pathogen* resist* plant*; pest resist* crop*; pest resistant livestock*; pest tracking; pesticide*; plant biotechnology*; plant gen* engineer*; plant genome editing; plant genomic*; yield of crops;
NU3 (Personalised information for healthy nutrition for all)	balanced nutrition; cheap food; Climate adapt* crop*; Climate adapt* livestock*; climate controlled greenhouse; diabete*; enhanced nutrition; fast food*; food choice*; food insecurity; food label*; food labelling; food polic*; food price; food processing; food production; good food choice*; health* diet*; health* food choice*; health* nutrition; healthy food choice; hunger; malnourishment*; malnutrition; nutrient content; nutriti* food; nutrition need*; nutrition shortage*; nutrition* information; nutrition* outcome*; nutrition* polic*; nutrition* security; nutrition* status*; nutritious food; obesities; obesity; poor diet*; poor dietary habit*; poor soil*; price of food; stunting; sugary drink*
NU4 (Precision & big data in agri-businesses)	agriculture big data; precis* agriculture*; precis* farm*

Note: to search for different word forms in Scopus we set "*" note at the end of terms. For example "food polic*" term runs the search for all word forms like food policy, food policies, food policymaker etc.

Scopus query search included also Scopus subject areas and Scopus subject categories (second level of classification within subject areas[16]) related to relevant thrusts of a specific domain. For example in the above given case, "Veterinary" subject area and also "Agronomy and Crop Science"; "Aquatic

[15] **Article-in-Press** is accepted article made available online before official publication. Review is a significant review of original research, also includes conference papers. **Letter** is a format of correspondence with the editor. Letters are individual letters or replies. Each individual letter or reply is processed as a single item. **Note** - Notes are short items that are not readily suited to other item types. They may or may not share characteristics of other item types, such as author, affiliation and references. **Editorial** – is a summary of several articles or provides editorial opinions or news. See more details at: https://www.elsevier.com/__data/assets/pdf_file/0007/69451/0597-Scopus-Content-Coverage-Guide-US-LETTER-v4-HI-singles-no-ticks.pdf

[16] Scopus classification is based on All Science Journal Classification Codes (ASJC). Scopus classification covers 27 subject areas and 313 subject categories. See in a more details on: https://service.elsevier.com/app/answers/detail/a_id/15181/supporthub/scopus/

Science"; "Food Science"; "Horticulture"; "Insect Science"; "Plant Science"; "Soil Science" subject categories within "Agricultural and Biological Sciences" subject area were selected.

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[16] Scopus classification is based on All Science Journal Classification Codes (ASJC). Scopus classification covers 27 subject areas and 313 subject categories. See in a more details on: https://service.elsevier.com/app/answers/detail/a_id/15181/supporthub/scopus/

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