SOUTH AFRICAN SCIENCE, TECHNOLOGY & INNOVATION INDICATORS REPORT

2023

Take a moment

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

NATIONAL ADVISORY COUNCIL ON INNOVATION

NATIONAL ADVISORY COUNCIL ON INNOVATION

2023 SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS REPORT

The 2023 South African Science, Technology and Innovation Indicators Report was compiled with the latest available data from a variety of organisations and institutions mandated to collect the data.

We welcome comments and suggestions that would enhance the value of the report.

Report published by the National Advisory Council on Innovation.

July 2023

To obtain copies, please contact:

The National Advisory Council on Innovation Secretariat
Tel.: 012 844 0252
Email: naci@dst.gov.za
Web: www.naci.org.za

ACKNOWLEDGEMENTS

The NACI Council would like to acknowledge the contributions of the following people to this report:

Expert team members

Dr Andrew Okem (University of KwaZulu-Natal)

Prof. Anastassios Pouris (University of Pretoria)

Mr Aubrey Mpungose (University of KwaZulu-Natal)

Prof. David Kaplan (University of Cape Town)

Prof. Johann Mouton (Stellenbosch University)

Dr Mziwandile Madikizela (private consultant)

Dr Oliver Mtapuri (University of KwaZulu-Natal)

Dr Petrus Letaba (University of Pretoria)

Dr Sithembiso Myeni (University of KwaZulu-Natal)

Dr Xolani Makhoba (Department of Science and Innovation)

NACI Secretariat

Ms Hlengiwe Mbatha

Mr Benny Nhlapo

Ms Phindi Nene

Members of the STI Indicators Reference Group

Dr Rasigan Maharajh (Institute for Economic Research on Innovation)

Dr Rebecca Maserumule (Department of Science and Innovation)

Dr Vijay Reddy (Human Sciences Research Council)

Prof. Kraemer Mbula, Erika (University of Johannesburg)

Prof. John Mugabe Ouma (University of Pretoria)

Prof. Michael Kahn (Independent Consultant)

Dr Azar Jammine (Econometrix)

Dr Olutoyin Olaitan (Walter Sisulu University)

The continuous contribution by the expert team members, STI indicators reference group and NACI secretariat team is much appreciated

Dr Mlungisi Cele

NACI Head

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

4IR	4th industrial revolution
AI	Artificial Intelligence
ARC	Agricultural Research Council
BRICS	Brazil, Russia, India, China and South Africa
CAGR	Compound Annual Growth Rate
CeSTII	Centre for Science, Technology and Innovation Indicators
CoGTA	Department of Cooperative Governance and Traditional Affairs
CREST	Centre for Research on Evaluation, Science and Technology
CSIR	Council for Scientific and Industrial Research
DALRRD	Department of Agriculture, Land Reform and Rural Development
DHET	Department of Higher Education and Training
DPME	Department of Planning, Monitoring and Evaluation
DSI	Department of Science and Innovation
EGDI	E-Government Development Index
EPO	European Patent Office
FTE	Full-Time Equivalent
GDB	Global Data Barometer
GDP	Gross Domestic Product
GERD	Gross Expenditure on Research and Development
GNI	Gross National Income
GVA	Gross Value Added
HC	Headcount
HSRC	Human Sciences Research Council
ICT	Information and Communications Technology
III	Inclusive Internet Index
IMC	Interministerial Committee
IMD	Institute for Management and Development
IP	Intellectual property
ITU	International Telecommunication Union
IoT	Internet of Things
M&E	Monitoring and Evaluation
MHT	Medium and High Technology
MNCS	Mean Normalised Citation Score
NACI	National Advisory Council on Innovation
NRF	National Research Foundation
NSC	National Senior Certificate
NSI	National System of Innovation
OECD	Organisation for Economic Co-operation and Development
PBR	Plant Breeders' Right

PCT	Patent Cooperation Treaty
PP	Proportion of Publications
RCA	Revealed Comparative Advantage
RDI	Research, Development and Innovation
RFS	Relative Field Strength
SA	South Africa
SAVCA	Southern Africa Venture Capital and Private Equity Association
SDG	Sustainable Development Goal
SET	Science, Engineering and Technology
SIC	Standard Industrial Classification
SMME	Small, Medium and Micro Enterprise
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
STIP	Science, Technology and Innovation Policy
TIA	Technology Innovation Agency
UCT	University of Cape Town
UK	United Kingdom
UN	United Nations
USD	United States Dollars
VC	venture capital
WHO	World Health Organisation
WIPO	World Intellectual Property Organization

FOREWORD BY THE CHAIRPERSON

I am pleased to present the Science, Technology and Innovation Indicators Report 2023. Science, Technology, and Innovation (STI) are increasingly viewed by governments – in both developed and developing countries – as a major driving force of national and socio-economic development.

The organising framework for this report is derived from the National Advisory Council on Innovation (NACI) Monitoring and Evaluation (M&E) framework. This framework examines inputs and enablers, flows and linkages, and outputs and impact to illustrate the current state of the country's National System of Innovation (NSI).

While there is a relatively low growth rate in the academic capacity of South Africa's university system, there has been no change in the relative shares of universities to strengthen their academic capacity in the Science, Technology, Engineering and Maths (STEM) fields over time. In 2010, staff in the STEM fields constituted 51,5% of all staff, and by 2021 this percentage was only 51,9%.

Development plans such as the OR University of Science Technology and Innovation will play a key role in enhancing the growth of critical skills in the STEM fields needed to create jobs, boost the economy and improve the lives of citizens.

Gross expenditure on research and development as a percentage of gross domestic product peaked at 0,76% during 2017/18 but has since declined to a low of 0,61% during 2020/21. Business-sector expenditure on Research and Development (R&D) has been declining since the beginning of the decade (2011/12) and declined further in 2020/21. The business sector's capacity to attract foreign funding is declining – overall and as a share of foreign funding. Within the business sector, there is no indication of any major areas that are exhibiting a notable technological dynamism – a sustained rise in their share of R&D. Alternative funding mechanisms, including international investment, are also needed to promote a smarter mix of funding that embraces the participation of several stakeholders in using STI to address various sustainability issues.

In terms of knowledge production and exploitation, applied research has consistently been the largest recipient of expenditure, its share increasing significantly up until 2017/18. After that time, there has been a decline in its share. Making a link between applied research and commercialisation, including patents for the benefit of society, is key and needs to be enhanced. South African resident patent numbers and share of domestic patents remain lower than a decade ago. There was a significant decline in the number of South African patents granted at the European Patent Office in 2021.

On a positive note, we have made improvements in STI human capital, particularly towards gender and race transformation. South African researchers have increased their collaborations with other countries and there has been an increase in the number of doctoral graduates employed in the higher education sector (66% compared to 61% employed by the sector during their doctoral studies).

The NACI council and Secretariat are hopeful that all NSI stakeholders, including policy makers, the social sector, private sector and non-governmental organisations, will find this report strategically useful in guiding future work in promoting innovation across South African society and the economy.

We hope that these observations will stimulate stakeholders to probe deeper into the underlying issues that stifle the emergence of a more successful and transformative innovation system, and work towards meaningful strategies to enhance the performance and impact of the NSI.

On behalf of the NACI Council, I sincerely thank all the contributors to this important report.

Mr Tilson Mphathi Manyoni

NACI Chairperson

1. EXECUTIVE SUMMARY

1.1. Purpose

The 2019 White Paper on Science, Technology and Innovation empowers the National Advisory of Innovation (NACI) to monitor and evaluate South Africa's national system of innovation (NSI). Consequently, NACI has produced the 2023 STI Indicators Report based on NACI's NSI monitoring and evaluation (M&E) framework. The report serves to provide "isibuko" or "mirror" the NSI.

The report offers an opportunity for NSI actors to pause and reflect about the state of and knowledge about the NSI through the data and information it provides. It deliberately offers little or no interpretation and recommendations. Complementary studies are being encouraged to deepen understanding and interpretation of the evidence contained in the report.

1.1.1. Research and development expenditure

- Gross expenditure on research and development as a percentage of gross domestic product declined from 0,76% in 2017/18 to 0,61% in 2020/21. There were large disparities in provincial R&D expenditure, with Gauteng contributing the highest (44%) followed by Western Cape (25%).
- Business-sector expenditure on R&D has been on a declining trend over the past decade, with a further decline in 2020/21 (10,8%).
- Business-sector funding for R&D is primarily focused on funding R&D within the business sector itself. In 2019/20 and 2020/21 there was a decline in the share of business-sector funding within the business sector (10%).
- Business-sector funding for R&D outside of the business sector is concentrated on higher education and science councils. Although there was a notable increase of R56 033 (8%) in business-sector funding for R&D outside of the business sector in 2020/21 compared to the previous year, such funding in science councils and higher education remains quite low, particularly for the latter. In 2020/21, the business-sector did not fund any government R&D.
- In recent years, the business sector has experienced a decline in its capacity to attract foreign funding for R&D. This trend continued up until 2020/21, during which foreign funding for R&D in the business sector experienced a 20% decrease.
- Businesses are funded by own funds, while higher education and science councils are funded by the government. Universities receive almost four times the amount that science councils receive from foreign funders. This may be an issue of policy concern.

In summary, business-sector expenditure on R&D has been on a declining trend over the decade and declined further in 2020/21. The share of business-sector expenditure on R&D has consistently declined. The business sector's capacity to attract foreign funding is declining – overall and as a share of foreign funding. Within the business sector, there is no indication of any major areas that are exhibiting a notable technological dynamism – a sustained rise in their share of R&D. While there has been an increase in R&D personnel in the business sector in 2020/21, the numbers employed are still well below the average for the decade. Moreover, declining business-sector R&D expenditures suggest further declines in the numbers employed in R&D in the business sector in the future.

1.1.2. STI human resources and expansion of research capacity

- A recurring policy imperative in the higher education sector is to increase the percentage of academic staff with doctoral degrees over time. The target of having 75% of academic staff achieve a doctoral qualification by 2030 is unlikely to be achieved as less than half of academic staff had a doctorate in 2021.

- The proportion of staff over 60 years of age (both men and women) increased from 7,3% in 2011 to 10,4% in 2020. This trend implies that public universities will lose about 10% of permanent staff with doctoral qualifications due to retirement within the next five years. However, the proportion of staff aged 20 to 29 declined from 7,9% in 2011 to 5,8% in 2020. Although there is an increase in the proportion of staff aged 30 to 39, this increase is lower than that of staff aged over 60. Therefore, there is a need to intensify young academic staff support instruments such as the New Generation of Academics Programme.
- As a result of the Department of Higher Education and Training's implementation of various programmes aimed at developing future generations of academics and building staff capacity, the gender gap among academic staff is gradually closing. Male and female researchers are approaching near parity.
- The percentage of staff in science, technology, engineering, and mathematics (STEM) fields has remained consistent over time. In 2010, the proportion of STEM staff among all staff was 51,5%, which rose slightly to 51,9% in 2021. This finding is, on reflection, not surprising. South African academics, once appointed on a permanent basis, cannot easily be replaced. Given that the typical academic career is around 40 years, universities have often been compared to large tankers that are exceedingly difficult to change course. For the percentage of staff in the STEM fields to increase significantly in relation to non-STEM (social sciences, humanities, education, economic and management sciences) staff, it would require a whole organisation design at many universities, creating more medical schools, engineering faculties and larger science faculties. The envisaged establishment of the new Oliver Tambo University of Science and Technology in Ekurhuleni, Johannesburg, is an example of the type of intervention that is required.
- Between 2010 and 2021, the proportion of permanent African academic staff at South African public universities increased significantly from 27% to 43%, while the proportion of permanent white academic staff decreased from 58% to 40% over the same period.
- Despite the increasing representation of both African and female permanent academic staff at public universities – with their share rising from 27,82% in 2011 to 37,51% in 2020 – the demographic composition of professors remains unbalanced. While there are more female professors, many of them are white, followed by African professors.
- The goal of increasing the numbers of graduates in science, engineering, and technology (SET) has been stated and repeated in multiple national policy documents post-1994. The 2019 White Paper on STI states that the country does not produce sufficient skills in SET for the economy. Despite various initiatives over the years to increase the output of SET graduates, the percentage of SET graduates as a proportion of all graduates has remained unchanged over the past 12 years.
- Since 2015, the relative percentage of female doctoral graduates in the STEM fields surpassed those of male graduates. There has also been an increase in the "production" of black doctoral graduates in STEM fields.
- Another positive development in the same domain has been the increase in the number of black doctoral graduates in STEM fields. From constituting about one third of all doctoral graduates in 2010, the share of black doctoral students in STEM fields increased to 44% in 2020.
- South African scientists have increased their research collaborations with the USA, Germany, UK, and Australia; all the other member states of BRICS; and a few other countries (Canada and a number of European countries).
- South Africa has managed to maintain its strong annual growth in scientific articles: an increase of the absolute numbers from 3 693 in 2000 to 27 052 in 2021. In Africa, South Africa is second after Egypt in the number of scientific publications.

1.1.3. STI outputs

- Despite various initiatives over the years to increase the output of SET graduates, the percentage of SET graduates as a proportion of all graduates has remained low over the past 12 years (up from 27% in 2010 to 29% in 2021). However, since 2015, the relative percentage of female doctoral graduates in the STEM fields surpassed those of male graduates. There has also been an increase in black doctoral graduates in STEM fields.
- South Africa's scientific publication output has seen a remarkable rise over the past two decades. The number of publications has increased from 3 693 in 2000 to 27 052 in 2021. However, despite this sustained increase in publications, the country's world share seems to have peaked at around 1% over the past five years.
- There has been a significant increase in the number of female authors contributing to university publications, rising from 31% in 2005 to nearly 42% in 2021. However, in the field of biotechnology, South Africa's world share of publications peaked in 2019, but experienced a decline in 2020 and again in 2021.
- South Africa has observed a significant increase in the number of domestic patents granted to residents in the country, yet it remains lower than a decade ago. There has been a steady decline in the number of South African patents granted at the European Patent Office in 2021. Regrettably, South Africa's world share of semiconductor patents has decreased from 0,015% in 2012 to 0,006% in 2021.
- In 2021, the sale of South African intellectual property (IP) increased compared to the previous year, but South Africa's share of receipts has significantly and consistently declined compared to all middle-income countries – dropping from 3,3% in 2016 to 0,8% in 2021. Payments abroad for the use of IP have also decreased since 2017, reflecting a slowdown in investment and economic growth. While there was an increase in payments abroad for the use of IP in 2021, it followed two years of decline and was still significantly lower than any year in the decade preceding 2018.

1.1.4. STI for socio-economic impact

- After a period of growth in the total number of researchers (by headcount), there has been a downward trend since 2018/19 (from 36 233 in 2017/18 to 34 072 in 2021/22). Between 2011/12 and 2017/18, the number of researchers in South Africa increased at a faster rate than the total employment in the country. Additionally, the number of researchers per thousand total employment also rose from 1,5 to 1,8 over this period. However, with the current decrease in the total number of researchers, this ratio is no longer increasing.
- Most South African researchers are based in the higher education sector (86,3% in 2020/21) and this trend is continuing. On the contrary, the business sector's share of total researchers in the country reduced from 15,2% in 2011/12 to 7,3% in 2020/21.
- Science councils have been on a downward spiral that began in 2017/18, with a decrease from 2 189 (3,9%) researchers in 2016/17 to 1 774 (2,9%) researchers in 2020/21.
- Manufacturing gross value added (GVA) and the share of medium and high technology (MHT) in manufacturing GVA saw a marginal increase in 2021.
- In 2021, there was an increase in MHT manufactured exports, but the overall share of MHT in manufactured exports remained relatively unchanged over the past decade. Although the number of MHT exporters, products, destinations, and transactions all increased slightly in 2021, they were still lower than they were five years ago.
- Formal employment in manufacturing decreased by 4,3% in 2020 and 1,0% in 2021. Overall, the numbers for formal employment in manufacturing in 2021 remained the same as they were a decade ago. Employment in MHT and MHT excluding motor vehicles also decreased in 2020 (-2% and -1,8%, respectively) but marginally increased in both categories in 2021 (by less than 1%). Employment in MHT and MHT excluding motor vehicles was 11% and 10% higher in 2021 compared to a decade ago, respectively.
- High-technology employment has increased in all provinces except the Eastern Cape and Western Cape, although

these increases have been from a low base. Conversely, medium-technology employment has declined in all provinces, while employment in the low-technology sector has dropped in all provinces except for the Northern Cape and the North West.

- The number of manufactured products, as well as the total number of products in which South Africa is competitive, has consistently declined. This decline rate has been accelerating since 2017, with a particularly significant drop in 2020.
- South Africa's ranking in the E-Government Development Index rose from 0,49 in 2012 to 0,74 in 2022.
- As a middle-income country, South Africa continues to confront several socio-economic challenges, such as poverty, high income and wealth inequalities, and escalating unemployment rates. A significant percentage of the population, approximately 20%, qualified as "extremely poor" in 2021. Other types of poverty remained high as well: lower-bound poverty at 29% and upper-bound poverty at 42%.
- In this light, embedding innovative systems with the country's policy agenda will require developing solutions to these socio-economic challenges.

2. SCIENCE, TECHNOLOGY AND INNOVATION ENABLERS

The STI enablers that are covered in this chapter are R&D funding and expenditure for all sectors, but specifically for the business sector, venture capital, STI human capital and digital infrastructure.

The report offers an opportunity for NSI actors to pause and reflect about the state of and knowledge about the NSI through the data and information it provides. It deliberately offers little or no interpretation and recommendations. Complementary studies are being encouraged to deepen understanding and interpretation of the evidence contained in the report.

2.1. Research and development expenditure trends in South Africa

Figure 2.1 shows the country's R&D expenditures (in nominal values) and Gross Expenditure on Research and Development (GERD) as a percentage of GDP for the period 2011/12 to 2020/21. R&D expenditures peaked in 2017/18 then declined subsequently. The graph of the R&D expenditures per GDP shows a peak of 0,76% during 2017/18 and subsequent decline to 0,61% during 2020/21.

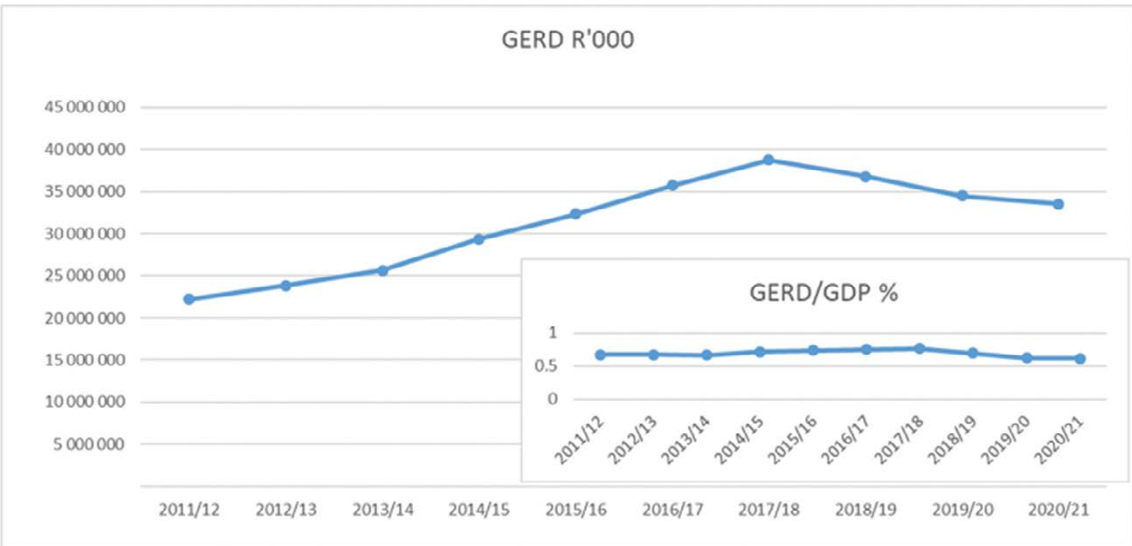


Figure 2.1: R&D expenditures and R&D expenditures per GDP

Source: HSRC and DSI, 2020/21 National Survey of Research and Experimental Development

Figure 2.2 shows the resources devoted to R&D in South Africa (ZAF) in comparison to other countries and regions. South Africa compares unfavourably with other countries. A number of countries spend around 3% of GDP on R&D. It should be noted that South Africa has a small number of researchers and a low ratio of R&D expenditures to GDP.

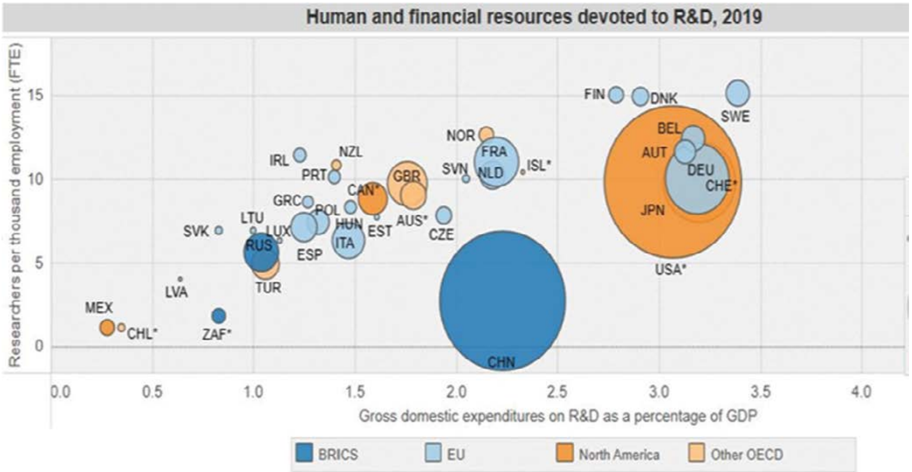


Figure 2.2: Human and financial resources devoted to R&D, 2019/20
Source: OECD, 2020 Research and Development Statistics

Figure 2.3 shows the different categories of research – basic, applied and experimental development – in South Africa during the period 2011/12 to 2020/21.

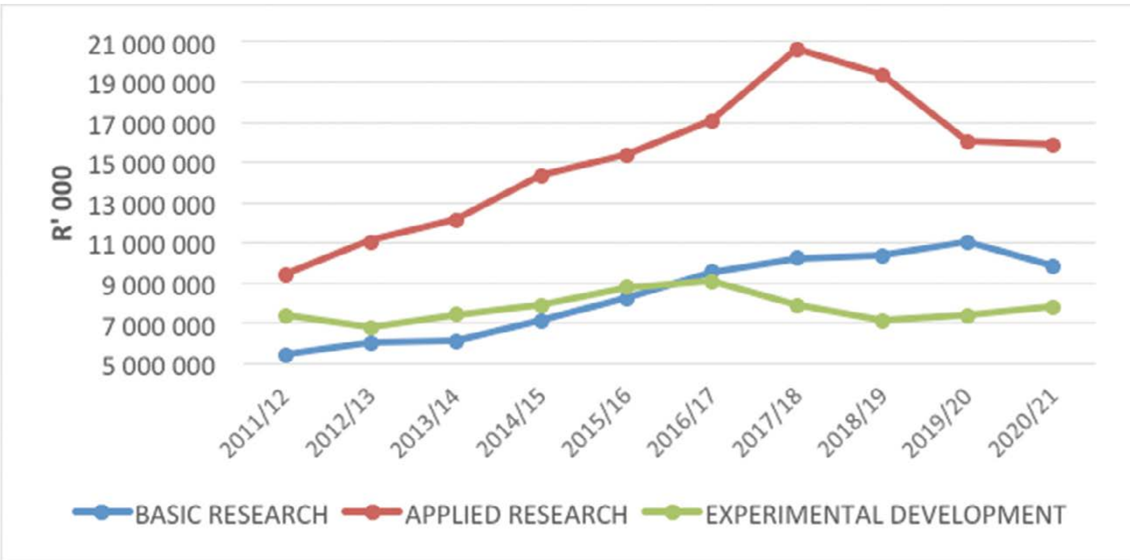


Figure 2.3: Research categories in South Africa
Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Applied research has consistently been the largest recipient of expenditures, its share increasing significantly until 2017/18. After that time, there has been a decline in its share.

Figure 2.4 shows the R&D expenditures of government, business, the higher education sector, science councils and not-for-profit organisations. The decline in the business sector after 2017/18 and the increase in higher education over the entire decade are evident.

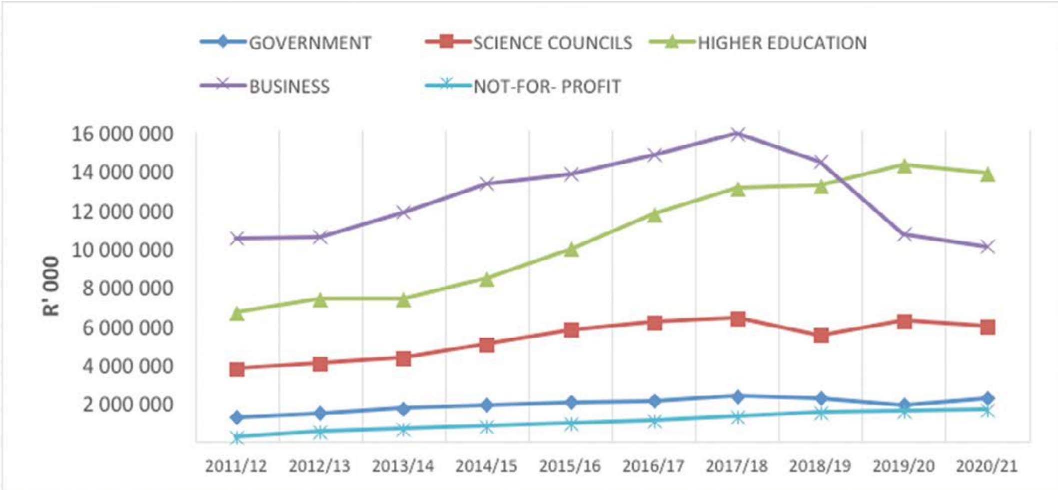


Figure 2.4: R&D expenditures by sector

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Figure 2.5 shows the percentage share of the various sectors on R&D expenditures. The continuously declining share of the business sector and the increase in the share of higher education are evident.

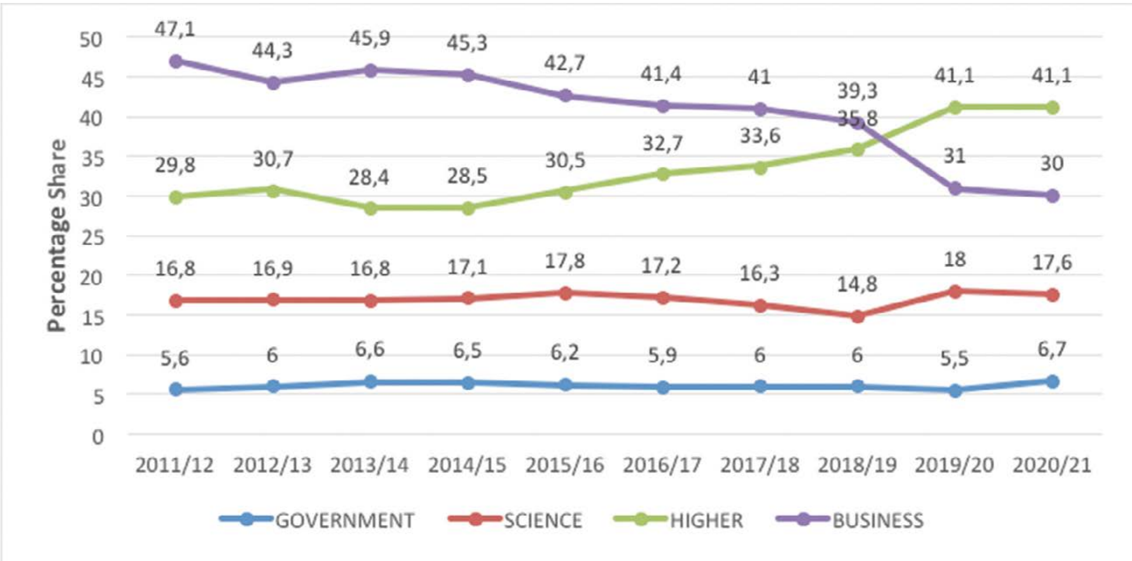


Figure 2.5: Percentage share of R&D expenditure by sector

Source: Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Figure 2.6 shows the investments in areas of relevance to South Africa. The health issues of tuberculosis, HIV and malaria are the highest during the whole period (R4,7 billion during 2020/21). Investments in environmental issues follow, with R3,7 billion at the end of the period and, and in biotechnology with R2,6 billion.

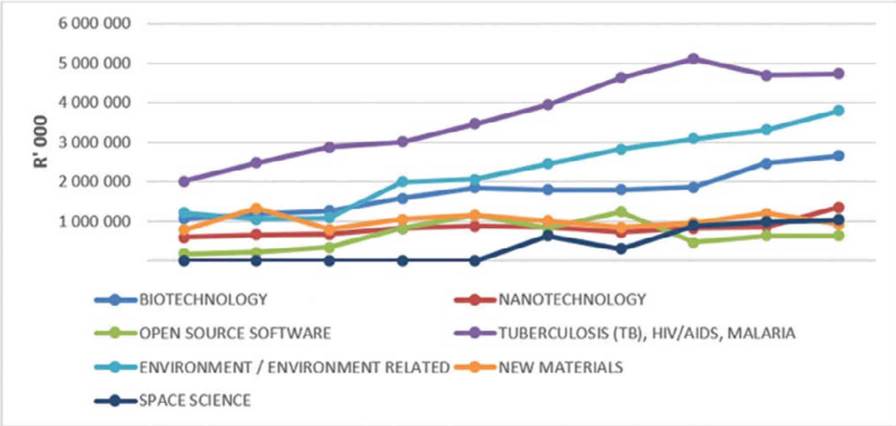


Figure 2.6: Investments in topics of South Africa's interest
Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Figure 2.7 shows the annual investments in equipment and postgraduate students. Investments in vehicles, plants etc. peaked during 2015/16 and then declined from R3 billion to R1,5 billion. It is important to notice that the equipment bought during 2015/16 are currently seven years and older.

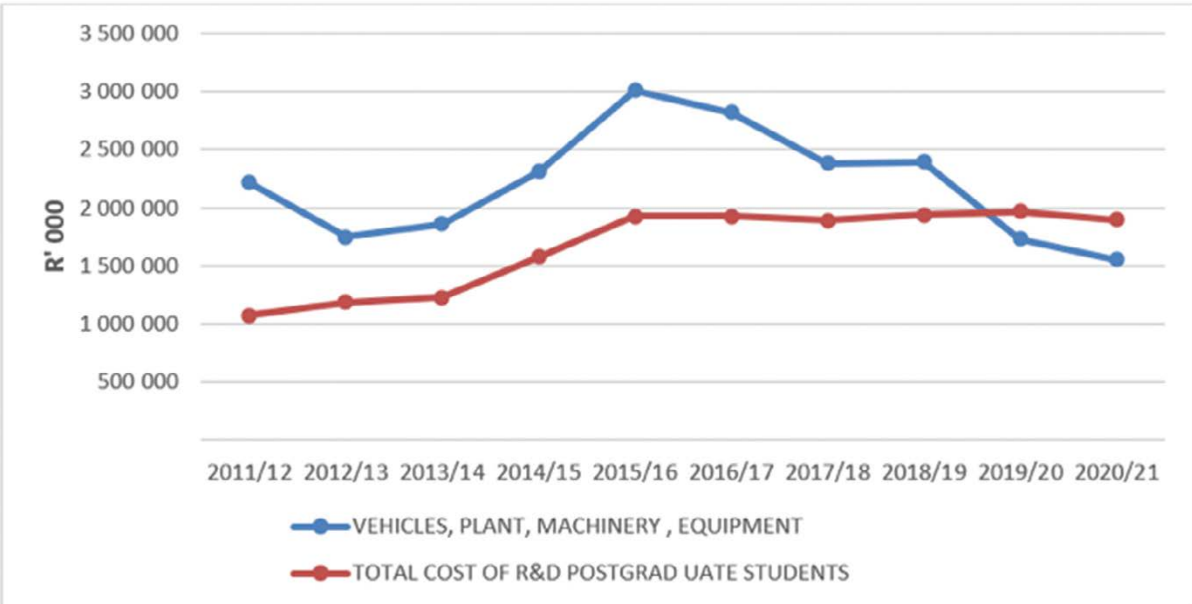


Figure 2.7: Investments in equipment and postgraduate students
Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Table 2.1 shows changes in funding in the main research fields during the same period 2011/12 to 2020/21.

Table 2.1: Changes in main research fields

Main research field	2011/12 R'000	2020/21 R'000	Changes (%)
Division 1: Natural sciences, technology	**18 924 485**	**25 894 833**	36,8
Mathematical sciences	636 153	799 796	25,7
Physical sciences	338 098	911 291	169,5
Chemical sciences	1 273 588	1 127 071	-11,5
Earth sciences	409 212	1 061 388	159,4
Information. computer and communication technologies	2 852 251	3 640 785	27,6
Applied sciences and technologies	2 114 322	1 367 857	-35,3
Engineering sciences	3 775 247	4 332 003	14,7
Biological sciences	1 350 716	1 530 697	13,3
Agricultural sciences	1 710 860	2 654 666	55,2
Medical and health sciences	3 819 180	7 404 019	93,9
Environmental sciences	439 719	440 186	0,1
Material sciences	166 411	328 498	97,4
Marine sciences	38 726	296 576	665,8
Division 2: Social sciences and humanities	**3 284 707**	**7 646 499**	132,8
Social sciences	2 790 339	6 597 460	136,4
Humanities	494 368	1 049 039	112,2
Total	**22 209 192**	**33 541 332**	**51,0**

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Marine sciences exhibit the highest growth but start from a small base. Earth sciences, social sciences and humanities exhibit growth above 100% during the period. Investments in applied sciences and technologies and chemical sciences declined during the period.

Table 2.2 shows the investment changes in various socio-economic objectives during the period. The areas showing the highest growth are economic frameworks; environmental knowledge; education and training; and health. Transport, manufacturing, construction and commercial services shrank during the period.

Marine sciences exhibit the highest growth but start from a small base. Earth sciences, social sciences and humanities exhibit growth above 100% during the period. Investments in applied sciences and technologies and chemical sciences declined during the period.

Table 2.2: R&D expenditure by socio-economic objectives

Socio-economic objectives	2011/12	2020/21	Changes (%)
	R'000	R'000	
Division 1: Defence	**1 069 289**	**1 594 793**	49,1
Defence	1 069 289	1 594 793	49,1
Division 2: Economic development	**12 174 897**	**14 081 873**	15,7
Economic development unclassified	0	0	-
Plant production and plant primary products	1 137 706	1 379 102	21,2
Animal production and animal primary products	565 729	707 826	25,1
Mineral resources (excluding energy)	1 065 384	1 401 816	31,6
Energy resources	273 390	303 671	11,1
Energy supply	676 491	932 553	37,9
Manufacturing	2 489 799	1 924 862	-22,7
Construction	392 440	305 468	-22,2
Transport	984 225	512 148	-48,0
Information and communication services	1 271 591	1 522 190	19,7
Commercial services	1 866 449	1 532 397	-17,9
Economic framework	611 868	2 262 348	269,7
Natural resources	839 825	1 297 494	54,5
Division 3: Society	**3 861 889**	**8 732 871**	126,1
Society unclassified	0	0	-
Health	2 301 764	5 397 930	134,5
Education and training	554 463	1 566 843	182,6
Social development and community services	1 005 662	1 768 099	75,8
Division 4: Environment	905 570	2 147 652	137,2
Environment unclassified	0	0	-
Environmental knowledge	398 977	1 180 361	195,8
Environmental aspects of development	216 406	419 346	93,8
Environmental and other aspects	290 187	547 945	88,8
Division 5: Advancement of knowledge	**4 197 547**	**6 984 142**	66,4

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

Figure 2.8 shows the main funders of businesses, higher education and science councils. Businesses are funded mainly by own funds. Higher education and science councils are mainly funded by the government. Universities receive almost four times the amount that science councils receive from foreign funders. This may be an issue of policy concern.

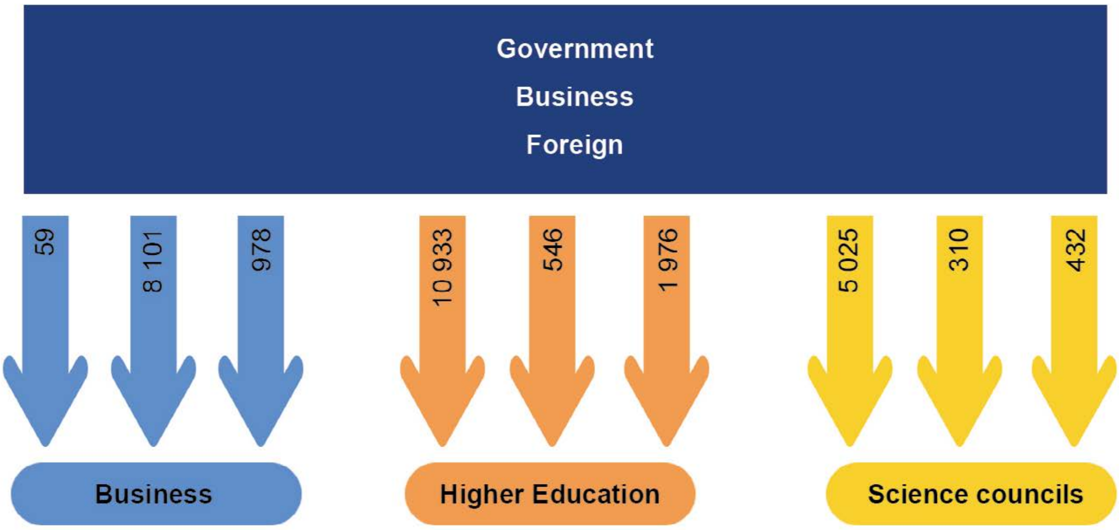


Figure 2.8: Main funders of business, higher education and science councils (R millions, 2020/21)
Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

2.2. Business expenditure and funding in research and innovation

R&D expenditure by the business sector has declined significantly since 2017. There was a further decline in 2020/21 in comparison to the previous year (10,8%). R&D expenditure by the business sector in 2020/21 is 40% lower than it was a decade ago.

Table 2.3: R&D expenditure by the business sector

	Constant 2015 Rand values	Year-on-year changes %
2011/12	12 894 165	-1,4 -3,5
2012/13	12 442 685	-3,5
2013/14	13 103 667	5,3
2014/15	14 028 004	7,1
2015/16	13 814 995	-1,5
2016/17	13 820 449	0
2017/18	14 058 812	1,7
2018/19	12 320 234	-12,4
2019/20	8 735 099	-23,1
2020/21	7 778 172	-10,8

Source: HSRC and DSI. 2020/21 National Survey of Research and Experimental Development

The share of the business sector in GERD has been declining consistently since 2011/12. There was a very significant decline in 2019/20. 2020/21 saw a further year-on-year decline. The share of the business sector in GERD in 2020/21 was 30%; a decade earlier, the business sector accounted for almost half of GERD.

Table 2.4: Business sector R&D expenditure as % of GERD

2011/12	47,1
2012/13	44,3
2013/14	45,9
2014/15	45,3
2015/16	42,7
2016/17	41,4
2017/18	41,0
2018/19	39,3
2019/20	31,0
2020/21	30,0

Source: HSRC and DSI "2020/21 National Survey of Research and Experimental Development"

Business-sector funding of R&D outside of the business sector itself is largely concentrated in higher education and science councils. Business-sector funding in both higher education and in science councils declined significantly after 2016/17. In 2020/21, there was a significant increase in business-sector funding of R&D in science councils. The total business-sector funding of R&D outside of the business sector in 2020/21 increased by R56 033 (8%) compared to the previous year. However, business-sector R&D funding in science councils and higher education is still well below the average for the decade, especially for the latter. The business sector did not fund any government R&D in 2020/21.

Table 2.5: Business-funded real R&D expenditure by sector

Year	Total	Government	Science councils	Higher education	Business	Non-profit
Constant 2015 Rand values (R' 000)						
2011/12	10 675 007	1 670	83 317	622 909	9 927 581	39 531
2012/13	10 772 761	13 538	159 765	679 801	9 890 302	29 302
2013/14	11 805 910	1 956	466 490	654 578	10 623 546	59 340
2014/15	12 646 438	306	235 253	934 373	11 409 923	66 582
2015/16	12 576 499	41 109	326 648	770 448	11 384 710	55 585
2016/17	13 132 872	1 178	451 759	847 716	11 767 978	64 239
2017/18	14 242 899	460	314 540	602 417	13 264 539	60 492
2018/19	12 393 817	3 935	176 217	385 170	11 757 152	61 343
2019/20	7 636 368	34 815	156 285	424 208	6 970 281	51 381
2020/21	7 002 702	0	240 322	423 485	6 273 979	58 915

Source: Data Supplied by CeSTII, Human Sciences Research Council.

Business-sector funding for R&D is largely concentrated on funding R&D in the business sector itself. In 2019/20 and 2020/21 there was a decline in the share of business-sector funding within the business sector. However, the share is close to 90%, only marginally lower than the share over the decade.

Table 2.6: Proportional business-funded R&D by sector (%)

Years	Government	Science councils	Higher education	Business	Non-profit
2011/12	0,0	0,8	5,8	93,0	0,4
2012/13	0,1	1,5	6,3	91,8	0,3
2013/14	0,0	4,0	5,5	90,0	0,5
2014/15	0,0	1,9	7,4	90,2	0,5
2015/16	0,3	2,6	6,1	90,5	0,4
2016/17	0,0	3,4	6,5	89,6	0,5
2017/18	0,0	2,2	4,2	93,1	0,4
2018/19	0,0	1,4	3,2	94,9	0,5
2019/20	0,5	2,0	5,6	91,3	0,7
2020/21	0,0	3,4	6,0	89,7	0,8

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

There has been a notable decline in the capacity of the business sector to attract foreign funding for R&D since 2015/16. There was a particularly significant decline in 2017/18 and again in 2018/19. There was a major year-on-year increase in 2019/20. However, in 2020/21 foreign funding for R&D in the business sector declined by 20%. In real terms, foreign-funded R&D in the business sector in 2020/21 was less than half of what it was in the first half of the decade.

Table 2.7: Foreign-funded real R&D in the business sector

Years (R'000)	Constant 2015 Rand values (R'000)
2011/12	1 925 097
2012/13	1 400 577
2013/14	1 364 505
2014/15	1 497 504
2015/16	1 532 766
2016/17	1 251 645
2017/18	420 866
2018/19	341 490
2019/20	953 652
2020/21	758 296

Source: CeSTII, Human Sciences Research Council

Over the decade, there has been a significant decline in the business sector's share of foreign-funded R&D in South Africa. In 2019/20, the business sector's share of foreign funding increased significantly. It declined year-on-year in 2020/21. The business sector's share of foreign funding remains low compared to much of the decade. Whereas a decade ago, almost half of all foreign funding for R&D in South Africa was destined for the business sector, in 2020/21, this was little more than one-fifth (21,9%).

Table 2.8: Business sector's share of foreign funding for R&D

Years	%
2011/12	46,9
2012/13	38,2
2013/14	37,0
2014/15	39,8
2015/16	36,4
2016/17	32,1
2017/18	12,1
2018/19	10,0
2019/20	25,1
2020/21	21,9

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

There has been a steady increase in the share of business-sector expenditure in R&D located in financial intermediation, real estate and business services (**see Table 2.9**). In 2010/11, financial intermediation, real estate and business services accounted for a little more than one-third of all business sector expenditures in R&D (33,9%). In 2016/17, it accounted for nearly half of all business sector expenditures on R&D. There was some decline thereafter, but the share of financial intermediation, real estate and business services was significantly higher in 2020/21 (42,3%), as compared with the previous year (37,7%).

Table 2.9: Proportional business-sector R&D expenditure by industry

	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Agriculture, hunting, forestry and fishing	2,7	3,1	3,5	3,5	3,2	2,5	3,9	6,6	6,6	4,5
Mining & quarrying	14,7	14,2	10,1	8,8	7,2	6,9	12,1	6,4	6,4	9,2
Manufacturing	32,9	32,2	33,9	32,2	27,8	28,2	21,9	32,3	32,3	28,8
Electricity, gas and water supply	3,6	3	4,1	3,2	3,7	4	4,9	7,1	7,1	7,1
Construction	0,1	0,1	0	0	0	0	0,1	0,0	0	0
Wholesale and retail	1,7	0,9	0,6	0,3	0,4	0,5	0,7	0,8	0,8	0,6
Transport, storage and communication	4,4	3,8	4,8	6,5	10,4	6,2	7,7	4,7	4,7	2,7
Financial intermediation, real estate and business services	37	40,1	40,3	42,8	44,3	48,8	44,3	37,7	37,7	42,3
Community, social and personal services	2,8	2,6	2,7	2,7	2,9	2,8	4,4	4,3	4,3	4,7
Total	100	100	100	100	100	100	100	100	100	100

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

As financial intermediation, real estate and business services expanded its share, the shares of most other sectors declined. Particularly significant has been the decline in the share of manufacturing. In 2020/21, the share of manufacturing was 28,8% – a significant reduction from its share in the previous year (32,3%). The share of mining and quarrying has declined sharply over the decade but increased significantly in 2020/21 (9,2%) as compared with the previous year (6,4%).

High-technology manufacturing as a percentage share of R&D in total manufacturing increased in 2018/19, in 2019/20, and significantly in 2020/21. However, the share in 2020/21 is only marginally greater than at the beginning of the decade. Overall, there is no clear tendency for the share of high-technology manufacturing to increase.

Medium-technology sectors account for more than two-thirds of manufacturing R&D. The most significant sector is petroleum products, chemicals, rubber and plastics. This sector has had a very significant increase in its share over the past two years and, in 2020/21, accounted for more than one-third of total manufacturing R&D. However, its share is currently similar to that of a decade ago.

There was a significant decline in transport equipment expenditure on R&D in 2020/21. R&D expenditures in transport equipment in 2019/20 was R381,5 million. In 2020/21, R&D expenditure was R96,8 million. The share of transport equipment declined from 11% in 2019/20 to 3,3% in 2020/21. This is less than one-third of this sector's share for the rest of the decade.

The share of the low-technology sectors in total manufacturing R&D increased over the decade. However, the share of low-technology sectors declined in 2019/20 and in 2020/21. The share of low-technology sectors in total manufacturing R&D in 2020/21 was marginally lower than earlier in the decade.

Overall, R&D data for the manufacturing sector for the decade do not suggest a clear tendency towards a higher technology intensity. The increase in the share of high-technology manufacturing in total manufacturing R&D over the past two years should be assessed in the light of a decline in real expenditure in R&D in the manufacturing sector. While there are fluctuations, the share of the different manufacturing sectors shows little movement over the decade.

Table 2.10: Percentage share of R&D expenditure in the manufacturing sector by technology intensity

	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
High technology	**18,0**	**18,9**	**19,6**	**15,7**	**12,8**	**15,3**	**14,0**	**15,4**	**15,6**	**19,6**
Radio, television, instruments, watches and clocks	18,0	18,9	19,6	15,7	12,8	15,3	14,0	15,4	15,6	19,6
Medium technology	**69,5**	**67,7**	**66,4**	**71,2**	**73,7**	**73,8**	**72,7**	**65,1**	**68,5**	**69,4**
Petroleum products, chemicals, rubber and plastic	38,9	32,8	33,1	40,8	40,5	41,3	37,8	25,3	33,7	37,9
Other non-metal mineral products	2,0	1,4	1,4	1,1	0,6	0,9	0,6	1,4	0,6	1,2
Metals, metal products, machinery and equipment	11,1	16,8	16,4	13,5	14,9	12,6	13,0	16,6	15,9	14,6
Electrical machinery and apparatus	8,7	9,0	6,7	6,7	8,6	11,1	14,2	11,8	7,3	10,4
Transport equipment	8,7	7,7	8,8	9,1	9,1	7,8	7,1	10,0	11,0	3,3
Low technology	**12,5**	**13,4**	**14,1**	**13,1**	**13,5**	**10,9**	**13,3**	**19,5**	**16,0**	**13,1**
Food, beverages and tobacco	8,0	9,2	9,0	8,1	8,5	8,0	10,2	15,7	13,1	9,4
Textiles, clothing and leather goods	0,0	0,1	0,8	0,8	0,2	0,2	0,5	0,4	0,3	0,6
Wood, paper, publishing and printing	2,3	1,5	1,6	1,6	2,2	2,1	2,0	2,4	2,3	2,7
Furniture & other Manufacturing	2,3	2,7	2,6	2,6	2,7	0,6	0,6	1,0	0,3	0,3

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

2.3. R&D personnel in the business sector

Reflecting on declining expenditure on R&D in the business sector, the numbers employed in R&D in the business sector declined by a little more than one-fifth (20,44%) in 2019/20 as compared with the previous year. However, in 2020/21, there was a significant increase (16,7%). This increase was surprising given the decline in R&D expenditures in the business sector in 2020/21 as compared with the previous year (-10,8%). The decline in R&D expenditures suggests that further declines in the numbers employed in R&D in the business sector are likely. Despite the increase in the last year, the numbers engaged in R&D in the business sector in 2020/21 remain well below the average for the decade.

Table 2.11: R&D personnel full-time equivalents in the business sector

2011/12	9 895
2012/13	11 322
2013/14	11 877
2014/15	12 928
2015/16	12 458
2016/17	12 549
2017/18	12 953
2018/19	11 691
2019/20	9 301
2020/21	10 860

Source: HSRC and DSI 2020/21 National Survey of Research and Experimental Development

In summary: business-sector expenditure on R&D has been declining over the decade declining further in 2020/21. The share of business-sector expenditure on R&D has consistently declined. The business sector's capacity to attract foreign funding is declining – overall and as a share of foreign funding. Within the business sector, there is no indication of any major areas that are exhibiting a notable technological dynamism – a sustained rise in their share of R&D. While there has been an increase in R&D personnel in the business sector in 2020/21, the numbers employed are still well below the average for the decade. Moreover, declining business-sector R&D expenditures suggest further declines in the numbers employed in R&D in the business sector in the future.

2.3.1. Venture capital investment

Venture Capital (VC) is an important source of funding to new enterprises, particularly for innovative and technology-based small firms. Seed and start-up capital represent the early-stage orientation of VC, the extent to which VC is supporting new ventures. In 2021, seed and start-up capital made up a larger share: 37,1% by value of deals (34% in 2020) and 56,2% by number of deals (44,6% in 2020).

Table 2.12: Venture capital investments contribution by stage of deal, all deals still valid, 2021

	Investment by value (%)	Investment by no. of deals %
Seed capital	3,9	13,8
Start-up capital	33,3	42,4
Later-stage financing	18,3	13,7
Growth capital	40,3	27,5
Buyout capital	1,3	1,3
Rescue/turnaround	2,6	0,9
Replacement capital	0,3	0,4

Source: SAVCA 2022 Venture Capital Industry Survey. Covering the 2021 calendar year

Over the past decade, there has been a steady increase in the value of VC investments and in the number of deals, with the rate of growth rising most rapidly after 2015 (see Table 3.13). The rate of growth slowed in 2020, but the value of investments continued to rise. However, in 2021, while the number of deals rose significantly (11,4%) the nominal value of investments declined (-5,8%).

Table 2.13: Venture capital investments per annum – value and number of deals

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Investments per year Value (R' millions)	288	183	273	372	933	968	1 067	1 230	1 390	1 310
Investments per year – number of deals	8	19	67	69	116	147	134	162	167	186

Source: SAVCA 2022 Venture Capital Industry Survey. Covering the 2021 calendar year

In 2021, food and beverage, fintech, manufacturing, consumer products and software were the leading sectors by value, accounting for almost half (49,3%) of VC investments (**see Table 2.14)**.

These sectors, together with business products and services (10%) accounted for over half (54,5%) of the number of deals. The most notable change in sectoral shares in 2021 has been the increasing share by value of fintech (6,9% in 2019; 8,8% in 2020 and 11,6% in 2021) and the declining share by value of manufacturing (13,8% in 2019; 11,7% in 2020 and 10,9% in 2021).

Table 2.14: Venture capital investment by sector share of value and number of deals, 2021

	By value (%)	By number of deals (%)
Food and beverage	11,9	6,0
ICT (fintech)	11,6	12,3
Manufacturing	10,9	7,6
Consumer products and services	7,7	7,7
ICT (software)	7,2	10,9
Healthcare (medical devices)	6,7	4,8
Healthcare (other)	6,3	6,6
Business products and services	5,2	10,0
Energy	4,6	2,5
ICT (telecommunications)	4,1	3,2
ICT (agritech)	3,8	1,3
Agriculture (not agritech)	3,0	3,2
ICT (electronics)	2,5	3,3
ICT (media) electronics/instrumentation	2,3	1,4
ICT (other)	1,9	1,6
Healthcare/Biotechnology	1,6	1,6
ICT (e-commerce)	1,5	2,8
Financial services (non-fintech)	1,5	3,7
ICT (security)	1,3	2,2
Distribution and logistics	1,2	2,2
ICT (online markets)	1,1	1,1
ICT (security)	1,0	2,2
ICT (edtech)	0,9	1,8
Mining, minerals and chemicals	0,4	0,6
Healthcare (life sciences)	0,4	0,9
Materials and resources	0,3	0,5
Healthcare (pharmaceuticals)	0,1	0,1
Retail	0,0	0,1

Source: SAVCA 2022 Venture Capital Industry Survey. Covering the 2021 calendar year

As shown in **Table 2.15**, VC investments are highly concentrated in the Western Cape and Gauteng. Indeed, there is very little VC activity outside of these two regions. In 2021, the Western Cape had the highest share by value (51,3%) and by number of deals (45,2%).

Table 2.15: Head office location by value and number of VC deals, all deals still active, 2021

	Number of deals (%)	Value of deals (%)
Western Cape	45,2	51,3
Gauteng	43,2	35,8
KZN	1,4	1,5
Rest of South Africa	-	4,5
Non-South Africa	9,6	6,9

Source: SAVCA 2022 Venture Capital Industry Survey. Covering the 2021 calendar year

VC activity in the African continent has been growing rapidly, with a sizeable increase in value invested in 2021. The value of deals increased almost five-fold, from $1,1 billion in 2020 to $5,2 billion in 2022. The number of deals more than doubled, from 319 in 2020 to 650 in 2021.

In the period 2014-2020, over one-fifth (21%) of the number of VC deals in Africa were in South Africa. Kenya (16%); Nigeria (15%) and Egypt (12%) were the other leading destinations. However, in 2021 South Africa's share of the number of VC deals on the African content fell to 17%. In 2021, Nigeria was the leading country destination for the number of deals (23%). Egypt (15%) and Kenya (13%) also increased their shares[1].

Nigeria was the leading country for VC deal value in 2021 (22%) and South Africa's share was 15%. For the first half of 2022, VC deal value in Egypt, Kenya, Nigeria and Ghana all significantly exceeded South Africa.

As VC in Africa has expanded dramatically, South African has lost its former dominance. "…South Africa's longstanding position as a titan in the venture capital industry is giving way in the face of increasing competition, entrepreneurial innovation and investment elsewhere in the continent's start up market. Nevertheless, South Africa continues to harbour strong investment activity…"

2.4. Science, technology and innovation human resources

A pipeline of the STI human resources covered in this section includes the high school terminal year, researchers employed in R&D and the academic staff profile.

2.4.1. National Senior Certificate human capital pipeline

Although a pass rate of 80,1% for the 2022 National Senior Certificate (NSC) cohort is impressive, what is worrying is a low throughput rate from grade 10 (66,8% in 2022). Throughput rate measures a percentage of learners from a specific grade 10 cohort who eventually write the NSC examination. As Table 3.16 shows, a pass rate for Technical Mathematics and Physical Science is high (81,0% and 74,7% respectively). For Mathematics, both participation rate and pass rate are low (37,2% and 55,0% respectively).

A pipeline of learners that are eligible to study a bachelor's degree from the 2022 NSC cohort is 37,2% of all the learners that wrote. Most of these learners are girls, which is aligned to a relatively large number of female learners sitting for the NSC exams. Lastly, Table 3.16 shows that 4,2% of the 2022 NSC cohort passed with overall distinction.

1 African Private Equity and Venture Capital Association, Venture Capital in Africa Report. April 2022: 17

Table 2.16: Summary of 2022 National Senior Certificate performance

Pass rate % Achieved	80,1
Maths achieved	55,0
% Technical Mathematics achieved	81,8
% Physical Science achieved	74,6
% Maths participation	37,2
% Bachelors	38,4
Bachelors – female	161 235
Bachelors – male	117 579
% Distinctions	4,2
% Throughput	66,8

Source: Department of Basic Education "NSC Exam Report 2022"

Table 2.17 shows a disaggregation of performance in the three selected subjects in terms of a type of a school. As has previously been shown by the Trends in International Mathematics and Science Study, the resources at home and school positively influence performance in Mathematics and Science. Fee-paying schools, on average, perform well in Mathematics, Physical Science and Technical Mathematics in comparison to no fee-paying schools. A huge difference can be seen in Mathematics results; fee-paying schools achieved 68,0% compared to 48,7% for no-fee-paying schools.

Table 2.17: NSC select subject performance by type of school, 2022.

Subject	Fee paying			Independent			No fee paying			All categories		
	Wrote	Achieved	% achieved	Wrote	Achieved	% Achieved	Wrote	Achieved	% Achieved	Wrote	Achieved	% Achieved
Mathematics	73 174	49 723	68,0	12 111	8 728	72,1	184 449	89 895	48,7	269 734	148 346	55,0
Technical Mathematics	5 156	4 582	88,9	120	80	66,7	9 381	7 331	78,1	14 657	11 993	81,8
Physical Science	98 733	76 026	77,0	8 887	7 667	86,3	101 384	72 184	71,2	209 004	155 877	74,6

Source: Department of Basic Education NSC Exam Report 2022

Independent schools perform even better than fee-paying public schools in Mathematics and Physical Science but perform relatively poorly in Technical Mathematics.

A proportion of the learners that passed Mathematics with distinctions is on a declining trend, from 3,2% in 2020 to 2,7% in 2022 (**see Table 2.18**). Physical Science shows a similar trend. The 2022 performance in terms of distinctions for Mathematics and Science is below the proportion of learners passing with distinction for the overall NSC (4,2%). This is even worse for Mathematical Literacy (1,7% in 2022).

Table 2.18: NSC Maths and Science performance with distinction

Subject	2020			2021			2022		
	Wrote	Achieved with distinction	% distinctions	Wrote	Achieved with distinction	% distinctions	Wrote	Achieved with distinction	% distinctions
Mathematics	233 315	7 424	3,2	259 143	7 725	3,0	269 734	7 304	2,7
Mathematical Literacy	341 363	5 696	1,7	441 067	10 005	2,3	450 005	7 792	1,7
Physical Sciences	174310	6368	3,7	196 968	6771	3,4	209 004	6 556	3,1

Source: Department of Basic Education NSC Exam Report 2022

Table 2.19 shows an upward increase in the proportion of learners achieving at 30% and above, 40% and above as well as 50% and above for Physical Science. This is not the case for Mathematics, as there was a decline in 2022 at all three achievement levels, following an increase in 2021.

Table 2.19: NSC Maths and Science performance by select achievement levels.

	% Achieved at 30% and above			% Achieved at 40% and above			% Achieved at 50% and above		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Mathematics	53,8	57,6	55,0	35,6	37,6	36,0	22,3	23,0	22,0
Physical Science	65,8	69	74,6	42,4	44,8	49,7	26,3	27,3	30,4

Source: Department of Basic Education NSC Exam Report 2022

In terms of gender, the throughput of male learners is very low for both Mathematics and Physical Science in comparison to female learners (**see Table 2.20**). As a result, more female learners passed both subjects than their male counterparts. However, the Mathematics pass rate is high for male learners (59,0%) in comparison to that of female learners (52,3%). For Physical Science, the pass rate is the same for both, at almost 75%.

Table 2.20: NSC Maths and Science performance by gender, 2022

	Mathematics			Physical science		
	Female	Male	Total	Female	Male	Total
Total wrote	162 341	107 393	269 734	125 770	83 234	209 004
Achieved at 30% and above	84 957	63 389	148 346	93 649	62 228	155 877
% Achieved	52,3	59,0	55,0	74,5	74,8	74,6

Source: Department of Basic Education NSC Exam Report 2022

2.4.2. Researchers' profile

As shown in **Figure 2.9**, following a period of increase in the total number of researchers (in headcount), the total number of researchers has been on a decrease since 2018/19 (from 36 233 in 2017/18 to 34 072 in 2021/22). The increase in the number of researchers in South Africa between 2011/12 and 2017/18 grew at a faster pace than that of the total employment in the country, as the number of researchers per thousand total employment also increased from 1,5 to 1,8. With a decrease in the total number of researchers, this ratio is also no longer growing.

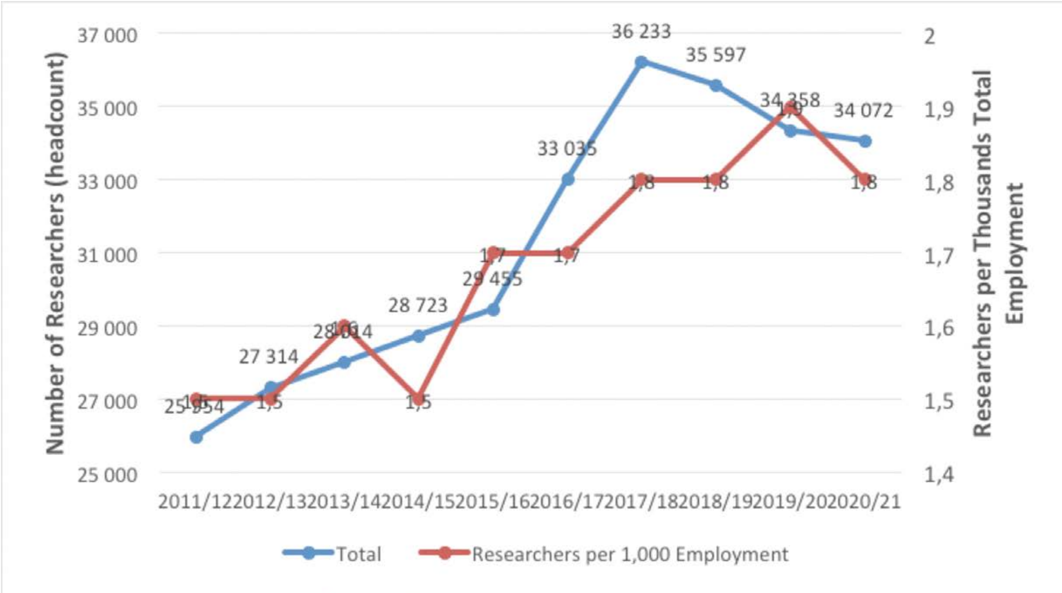


Figure 2.9: Researchers and researchers per thousand total employment

Source: HSRC and DSI 2020/21 National Survey on Research and Experimental Development

Most South African researchers are based in the higher education sector (86,3% in 2020/21) and this trend is continuing. On the contrary, business sector's share of total researchers in the country reduced from 15,2% in 2011/12 to 7,3% in 2020/21.

As shown in **Figure 2.10,** the sectors such as government, not-for-profit organisations and science councils contribute very little in terms of employment of researchers. Science councils have been on a downward spiral that began in 2017/18, with a decrease from 2 189 (3,9%) researchers in 2016/17 to 1 774 (2,9%) researchers in 2020/21.

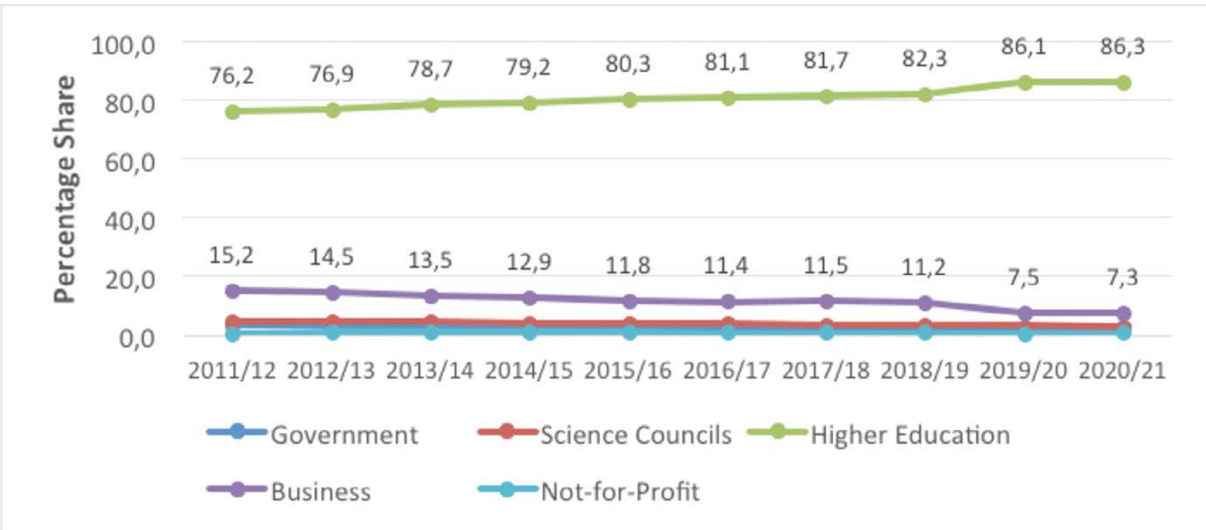


Figure 2.10: Researchers per sector of employment

Source: HSRC and DSI 2020/21 National Survey on Research and Experimental Development

Over the past years, there has been an increase in the proportion of female researchers, although it seems that this increase has slowed down during 2019/20 to 2020/21 (**see Figure 2.11**).

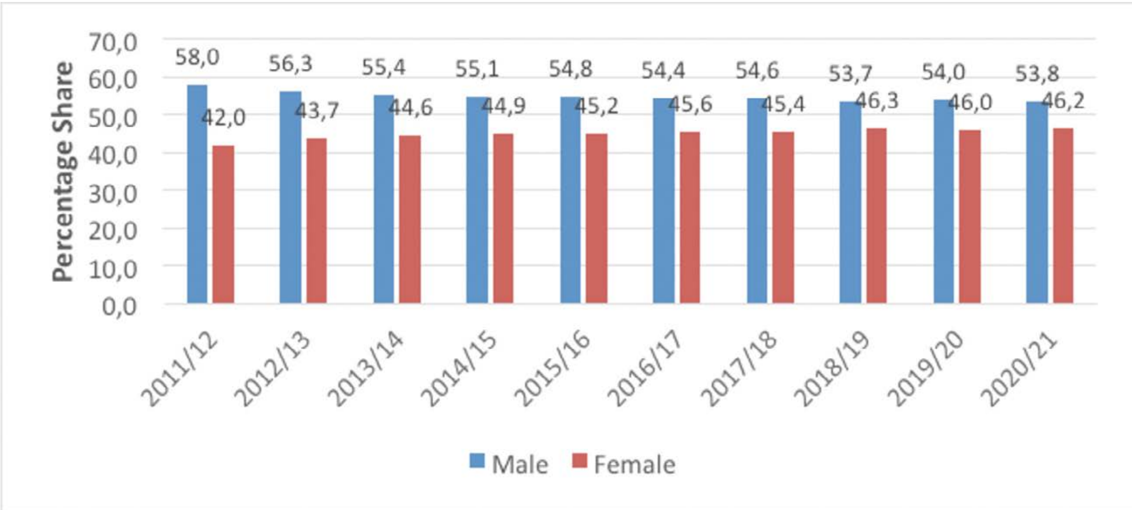


Figure 2.11: Researchers by gender

Source: HSRC and DSI 2020/21 National Survey on Research and Experimental Development

Another key transformation indicator is the distribution of researchers by race categories. As shown in **Figure 2.12**, the researchers' profile is progressively transforming, as indicated by an increase in proportion of the designated groups. Since a survey started to incorporate non-South African researchers, the data shows that they are more than 10% of the South African researchers' workforce.

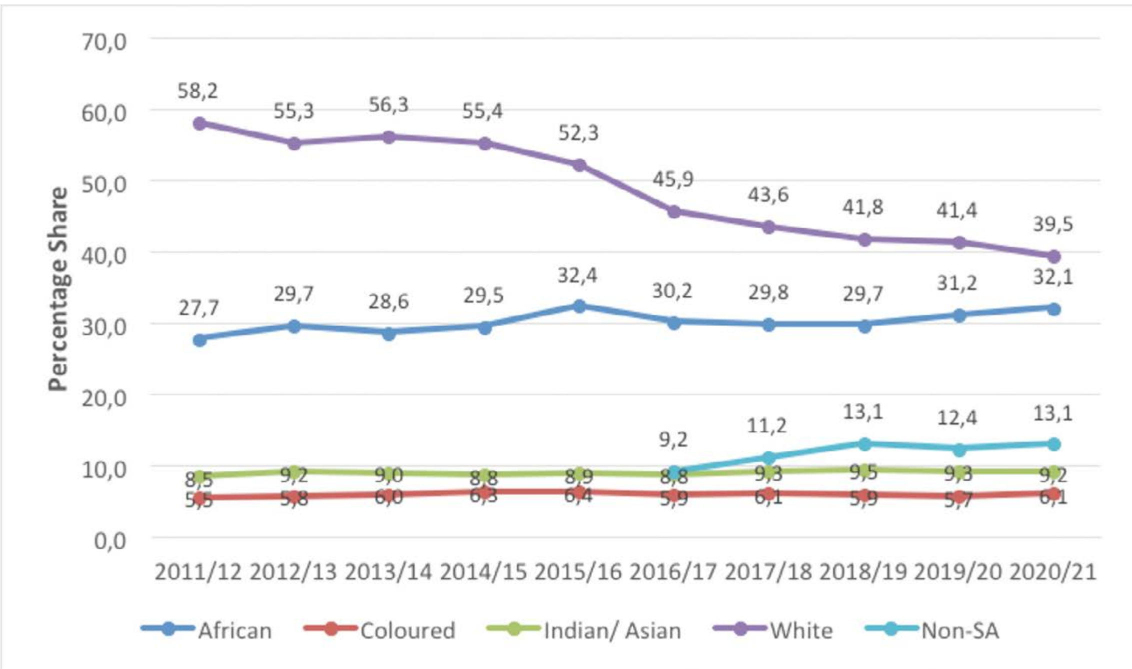


Figure 2.12: Researchers per race classification

Source: HSRC and DSI 2020/21 National Survey on Research and Experimental Development

2.4.3. Higher education academic staff capacity and diversity

The core of the university system is made up by its academic staff, especially its research and instructional staff. It is the academic staff who pursue the core missions of teaching, supervision, knowledge production and public engagement. For the purposes of this report, it is this core of highly qualified staff that also provides the knowledge-productive capacity of the system that results in new scientific discoveries, research findings and, ultimately, new technologies and innovation.

As **Figure 2.13** shows, the compound annual growth rate (CAGR) of HC of permanent academic staff was 1,7% between 2010 and 2021. The CAGR for the full-time equivalent (FTE) staff is higher, at 2,1% between 2010 and 2021.

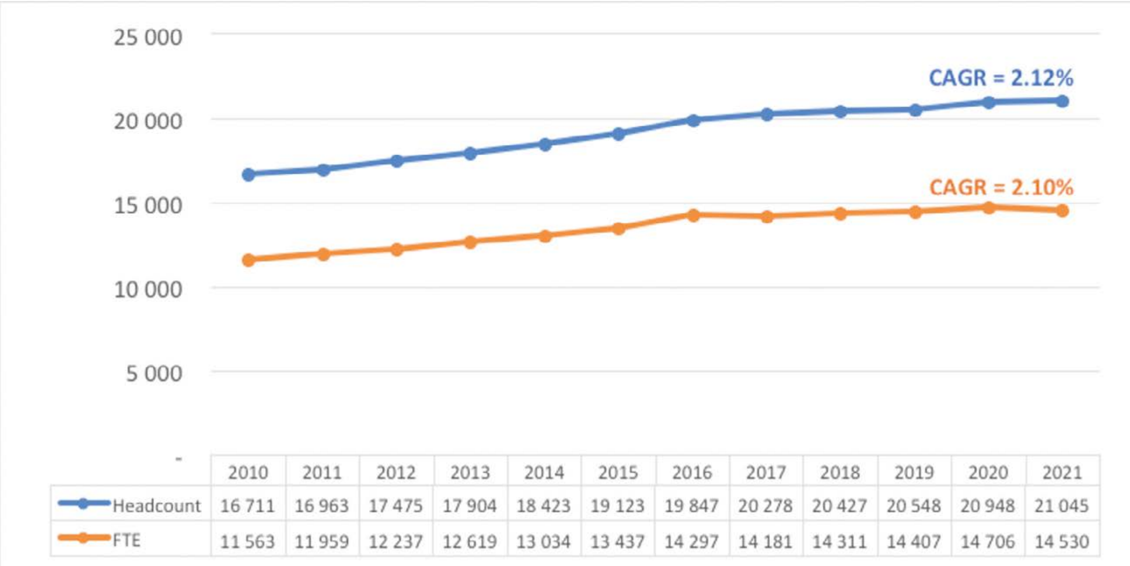


Figure 2.13: Trend in number of permanent academic staff (HC and FTE)
Source: CREST, Stellenbosch University

The results show a steady and linear, albeit small, rate of increase over time in the growth of the academic capacity of the system. It is worth pointing out that this growth occurred during a time where three new universities (Sol Plaatje University, Sefako Makgatho University and University of Mpumalanga) were established that required new staffing. Perhaps more helpful is a comparison of the growth rates of staff with the overall increase in students (both undergraduates and postgraduate students) in **Figure 2.14.**

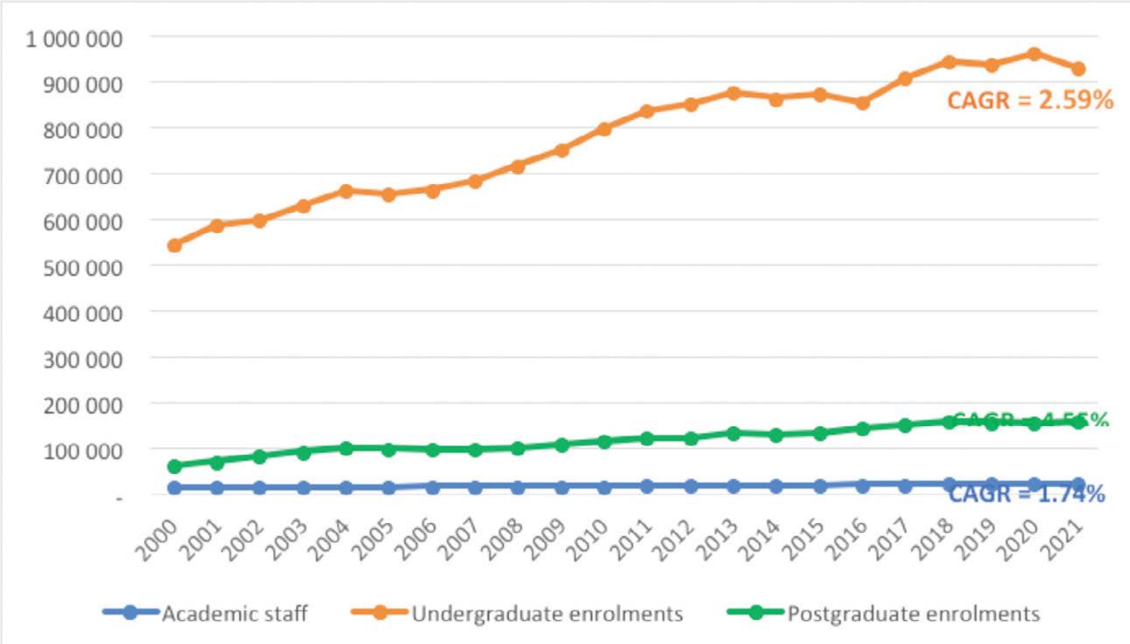
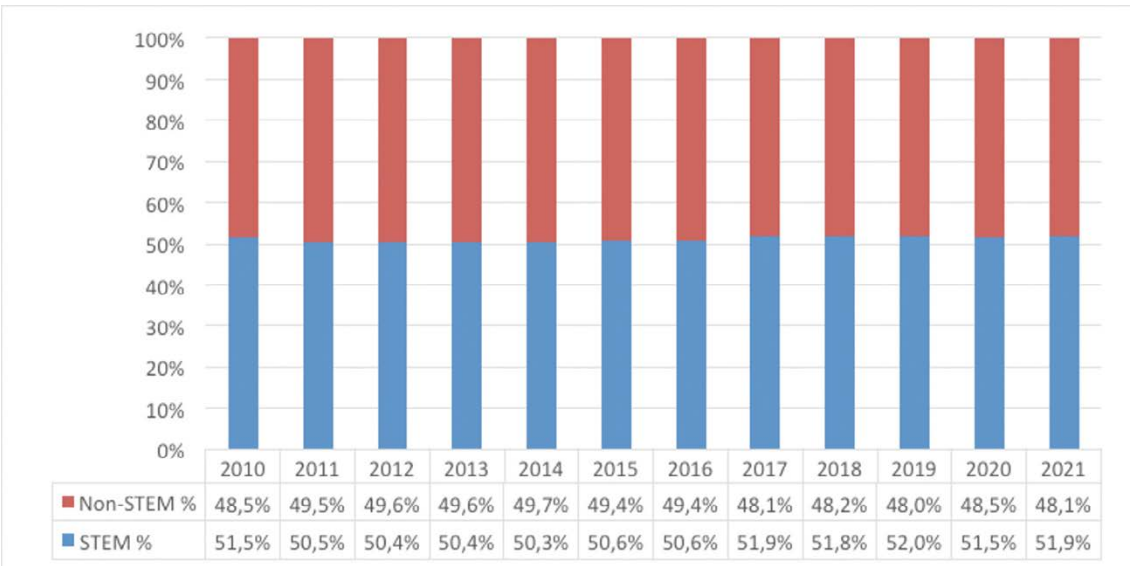


Figure 2.14: Comparison in the growth rates of academic staff and students
Source: CREST, Stellenbosch University

As a consequence of the higher growth rates of both undergraduate and postgraduate student enrolments, compared to the increase in academic capacity, the average student-to-staff ratio increased from 41:1 in 2000 to 52:1 in 2021.

Besides the relatively low growth rate in the academic capacity in South Africa's university system, there are two other trends worth pointing out. The first concerns the question of whether universities have managed to strengthen their academic capacity in the STEM fields over time, as is highlighted in many national policy documents. **Figure 2.15** presents the trend over time by disaggregating academic staff into either STEM or non-STEM (social sciences, humanities, education, economic and management sciences) fields. It is clear from the data that there has been no change in these relative shares. In 2010, staff in the STEM fields constituted 51,5% of all staff and by 2021 this percentage was 51,9%.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Non-STEM %	48,5%	49,5%	49,6%	49,6%	49,7%	49,4%	49,4%	48,1%	48,2%	48,0%	48,5%	48,1%
STEM %	51,5%	50,5%	50,4%	50,4%	50,3%	50,6%	50,6%	51,9%	51,8%	52,0%	51,5%	51,9%

Figure 2.15: Trends in percentage of staff (FTE) in STEM and non-STEM [2]

2 The reason for the shorter time frame (2010 to 2020) in this graph is related to the radical change in the classification of education subject matter (CESM) in 2009. The change in the classification system makes it impossible in some fields – most notably in the life sciences – to compare staff and student numbers before and after 2010. Hence the decision to report on the trend since 2010.

This finding is, on reflection, not surprising. South African academics, once appointed on a permanent basis, cannot easily be replaced. Given that the typical academic career is around 40 years, universities have often been compared to large tankers that are very difficult to change course. For the percentage of staff in the STEM fields to increase significantly in relation to the non-STEM staff, it would require a whole organisation design at many universities, creating more medical schools, engineering faculties and larger science faculties. The envisaged establishment of the new Oliver Tambo University of Science and Technology in Ekurhuleni, Johannesburg, is an example of the type of intervention that is required.

A recurring policy imperative in the higher education sector is to increase the percentage of academic staff with doctoral degrees over time. This goal, which is laudable, was expressed in early national policy documents such as the Ten-Year Innovation Plan (2008) and repeated in the National Development Plan (2010). The target of having 75% of academic staff achieve a doctoral qualification by 2030 has, however, turned out to be elusive and, in hindsight, not evidence based. The data, as shown in **Figure 2.16**, shows that by 2021 less than half (48%) of all permanent academic staff have a doctorate. It is also clear from the trend over the past 17 years, that it is highly unlikely that the target of 75% will be achieved in the near future.

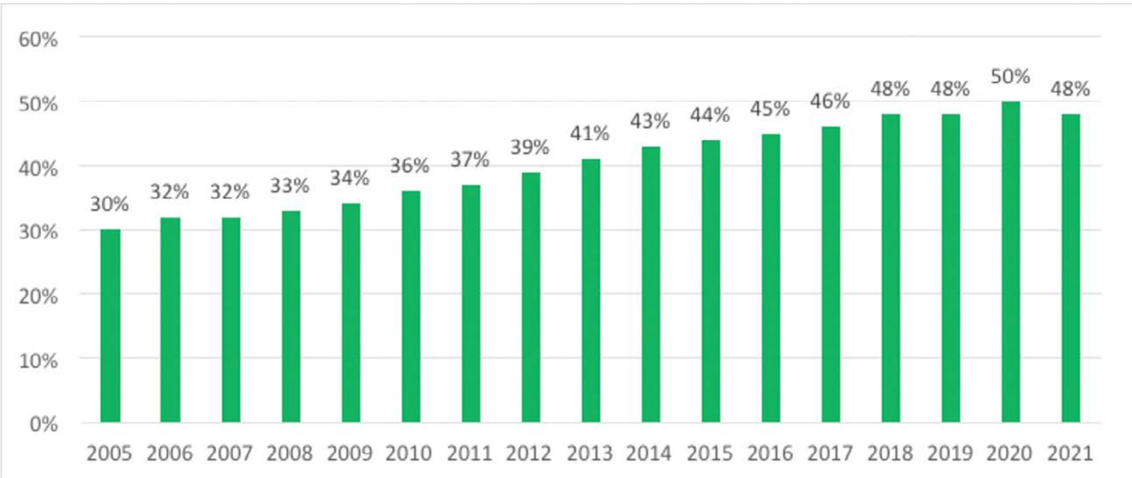


Figure 2.16: Trend in percentage of staff with doctoral qualifications

Table 2.21 provides some explanation behind the growth pattern of permanent academic staff with a doctoral qualification. An increasing proportion of staff are over 60 years of age (both men and women), from 7,3% in 2011 to 10,4% in 2020. This implies that in less than five years public universities will lose about 10% of permanent staff with doctoral qualifications due to retirement.

On the contrary, for both genders, the proportion of staff in this category that are aged 20 to 29 is on a decline (from 7,9% in 2011 to 5,8% in 2020). Although there is an increase in the proportion of staff aged 30-39, such increase is lower than that of staff aged above 60. Therefore, there is a need to intensify young academic staff support instruments such as the New Generation of Academics Programme.

Table 2.21: Permanent academic staff with PhD by age and gender

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
% Share of academic staff with doctorate qualification										
20 – 29	**7,9**	**7,9**	**7,8**	**7,6**	**7,3**	**7,4**	**7,0**	**6,5**	**6,2**	**5,8**
Male	3,2	3,3	3,3	3,2	3,1	3,3	3,1	2,9	2,8	2,6
Female	4,7	4,6	4,5	4,4	4,2	4,1	3,9	3,6	3,4	3,2
30 – 39	**27,1**	**26,7**	**26,2**	**26,2**	**26,5**	**26,5**	**27,0**	**27,3**	**27,5**	**27,7**
Male	13,8	13,5	13,3	13,2	13,1	12,9	12,9	13,0	13,1	13,3
Female	13,3	13,1	12,9	13,0	13,4	13,6	14,2	14,3	14,4	14,4
40 – 49	**30,3**	**30,5**	**30,7**	**30,6**	**30,6**	**30,7**	**30,3**	**30,2**	**29,9**	**29,8**
Male	16,8	16,9	16,9	16,7	16,3	16,3	16,0	15,7	15,5	15,1
Female	13,6	13,6	13,9	13,9	14,3	14,3	14,3	14,5	14,5	14,6
50 – 59	**27,3**	**27,1**	**26,9**	**27,0**	**26,5**	**26,3**	**26,2**	**26,4**	**26,5**	**26,3**
Male	16,3	16,0	15,7	15,5	15,0	14,7	14,6	14,6	14,6	14,3
Female	11,0	11,1	11,2	11,5	11,5	11,5	11,6	11,7	11,9	12,0
60+	**7,3**	**7,8**	**8,3**	**8,6**	**9,0**	**9,1**	**9,5**	**9,6**	**10,0**	**10,4**
Male	5,2	5,5	5,7	5,8	5,9	5,9	5,9	5,9	5,9	6,2
Female	2,1	2,3	2,7	2,7	3,1	3,2	3,6	3,7	4,1	4,2

Source: NRF Information Portal

In 2015 the DHET launched the Staffing South Africa's Universities Framework to develop future generations of academics and to build staff capacity. In addition to the New Generation of Academics Programme, its other programmes include the Nurturing Emerging Scholars Programme and Existing Academics Capacity Enhancement Programme.

The results, as far as gender is concerned (**Figure 2.17**), show the gradual closing of the gap between male and female researchers, with the result that near parity has been achieved.

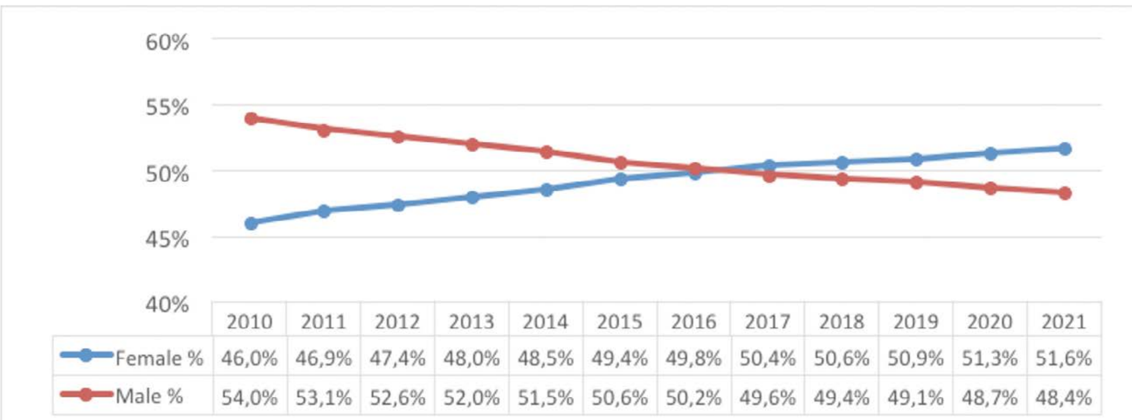


Figure 2.17: Percentage of academic staff by gender

Source: CREST, Stellenbosch University

The percentage share of permanent African academic staff at South African public universities continues to increase, reaching 43% in 2021 **(Figure 2.18)**. Another notable trend is a decrease in a proportion of permanent white academic staff from 58% in 2010 to 40% in 2021.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
White	58%	57%	56%	54%	53%	51%	48%	47%	45%	43%	41%	40%
Indian / Asian	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
Coloured	6%	7%	7%	7%	7%	7%	8%	8%	8%	8%	8%	8%
African	27%	27%	28%	30%	31%	33%	35%	37%	39%	40%	42%	43%

Figure 2.18: Proportion of permanent academic staff by race
Source: NRF Information Portal

Although both African and female permanent academic staff continue to increase their share, the demographics of professors at public universities remain unbalanced. As **Table 2.22** shows, in 2020 female professors represented about 37,51% of all permanent professors (including associate professors), up from 27,82% in 2011. The majority of these female professors are white, followed by Africans. The proportion of permanent female academic professors is on an upward trend for all the races.

Table 2.22: Proportion of permanent academic female professors to total professors by race

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
					%					
African female	2,31	2,85	3,39	4,12	4,53	5,10	5,78	6,06	6,18	6,63
Coloured female	1,27	1,44	1,57	1,62	1,82	1,75	1,85	1,98	2,17	2,05
Indian female	1,94	2,03	2,04	2,02	2,13	2,35	2,59	2,68	3,09	3,22
White female	23,31	23,10	23,23	23,50	23,64	23,80	24,20	24,31	24,75	24,99
Other female	0,26	0,15	0,22	0,38	0,36	0,41	0,54	0,54	0,55	0,62

Source: NRF Information Portal

2.5. Digital infrastructure

Digital infrastructure plays an important role in socio-economic development. It is comprised of the physical resources that are necessary to enable the use of data, computerised devices, methods, systems and processes. Access to digital infrastructure has become indispensable to the functioning of society and citizens' quality of life. Digital capabilities are essential to ensure a country's growth and economic resilience and are key enablers for innovators and entrepreneurs.

This section presents selected indicators of South Africa's digital economy. These are the digital competitiveness ranking, infrastructure, access and enablers.

2.5.1. Digital competitiveness of South Africa

The Institute of Management and Development (IMD) World Digital Competitiveness Ranking was created to assess the capabilities and readiness of economies to undertake the process of digital transformation. Digital competitiveness is defined as the capacity of an economy to adopt and explore digital technologies leading to the transformation in government practices, business models and society in general.

As shown in **Table 2.23**, in 2022 South Africa was ranked 58th out of 63 countries, a slight improvement from 60th in the previous year. The best ranking of the country was in 2019, with a ranking of 48. In 2022, compared to other BRICS countries, South Africa had the lowest ranking far below the leading country China (ranked 7th).

Table 2.23: Digital competitiveness ranking comparison with BRICS

	2018	2019	2020	2021	2022
Brazil	55	57	57	51	52
China	31	30	22	16	7
India	51	48	44	48	44
Russia	42	40	38	43	-
South Africa	49	48	60	60	58

Source: IMD World Digital Competitiveness Reports, 2016-2021

To determine the competitiveness ranking, the IMD ranks countries according to how they fare in the following three factors: knowledge, technology and future readiness.

The knowledge factor refers to intangible infrastructure that enables the discovery, understanding and learning of new technologies, in turn leading to digital transformation. This is captured by indicators that measure the quality of human capital available in a country, as well as the level of investments in education and research and their outcomes (e.g., registered patent grants in high-tech fields and employment in the scientific and technological sectors).

The technology factor assesses the overall context facilitating the development of digital technologies. This includes criteria that assess the impact of regulation in encouraging innovation in the private sector, the availability of capital for investments and the quality of the technological infrastructure.

The future readiness factor examines the degree to which technology is adopted by governments, business and society at large. This factor includes indicators such as the diffusion of e-commerce, industrial robots and data-analytics tools in the private sector as well as the strength of those cyber-security measures in place.

Table 2.24 shows the five-year evolution of the sub-factors' rankings. South Africa performs poorly across all factors. South Africa's performance has been declining, although there was a slight improvement in 2022 compared to 2021.

Table 2.24: Factor-level performance of South Africa

Factor	2018	2019	2020	2021	2022
Knowledge • Talent • Training and education • Scientific concentration	52	54	60	60	54
Technology • Regulatory framework • Capital • Technological framework	52	51	55	59	58
Future readiness • Adaptive attitudes • Business agility • ICT integration	43	44	57	59	59

Source: IMD Digital Competitiveness Reports, 2018-2022

2.5.2. Digital infrastructure, access and enablers

South Africa's digital development was assessed using the International Telecommunication Union (ITU) ICT indicators. The ITU is a UN institution that measures ICT development globally. It is based on three indices: infrastructure and access, internet use, and enablers and barriers.

Infrastructure and access

The ITU indicators for infrastructure and access examine network coverage, mobile and telephone access and ICT access at home. The following table compares South Africa's ICT infrastructure and access to other BRICS countries. As Table 2.25 shows, network coverage and mobile cell ownership are 100%, one of the highest among the BRICS countries.

Table 2.25: Comparison of infrastructure and access in South Africa with BRICS

Country	Network coverage	Mobile phone ownership (individuals also owning a mobile phone)	ICT access at home		Mobile and fixed telephone subscriptions	Mobile and fixed broadband subscriptions	
			Households with Internet access at home	Household with computer at home	Mobile-cellular subscriptions per 100 inhabitants (2021)	Active mobile-broadband subscriptions per 100 inhabitants (2021)	Fixed broadband subscriptions per 100 inhabitants (2021)
SA	100%	78%	63%	23%	169	116	3
Brazil	90%	89%	83%	45%	102	96	19
Russia	99%	98%	84%	73%	169	108	24
India	99%	-	24%	11%	82	54	2
China	100%	-	-	-	122	105	38

Source: ITU [3]

Mobile cellular subscriptions and active mobile broadband subscriptions are also high. However, the number of households with internet access at home is moderate (63%) while the percentage of homes with a computer is only 23%.

Internet use

Access to computers and internet technology remains a crucial resource for connecting people to the information and skills they need in an increasingly digital world. The data in **Table 2.26** shows that the use of the internet has increased from 54% in 2016 to 70% in 2020 among 25 to 74-year-old individuals.

Table 2.26: Percentage of population aged 25-74 using the internet.

	2016	2017	2018	2019	2020
South Africa	54	56	62	68	70
Brazil	61	66	70	74	81
Russia	73	76	81	83	85
India	17	18	20	29	43
China	82	83	84	86	88

Source: ITU

However, when compared to the other BRICS countries, South Africa had the second-lowest internet use in 2020, which is far below the leading country, China (88%).

3 International Telecommunication Union (2020). Measuring digital development. Facts and Figures 2020. Geneva: ITU.

Enablers and barriers

ICT prices

Affordable and accessible high-speed broadband is an important enabler for competitiveness across many areas. The ITU has developed a framework for price statistics, using ICT price baskets, which are internationally comparable units of ICT services. The price baskets are defined by the Expert Group on Telecommunication Indicators and revised occasionally to adjust for changes in the global market for ICT services.

Table 2.27 compares the cost of ICT services in South Africa with BRICS countries. As the data shows, in 2021, South Africa had the highest cost across the basket of services. However, some of the costs are below the international target of 2,5% Gross National Income (GNI) per capita that was proposed by the expert group.

Table 2.27: Comparison of ICT costs among BRICS countries, 2021

	South Africa	Brazil	Russia	India	China
Fixed broadband basket as a % of GNI per capita	5,4	3,5	0,9	3,3	1,1
Mobile data and voice basket as a % of GNI p.c.	4,8	1,1	0,8	1,1	0,7
Mobile data and voice basket as a % of GNI p.c.	2,4	1,1	0,7	1,1	0,5
Mobile broadband basket as a % of GNI p.c.	2,3	1,0	0,4	1,1	0,5
Mobile cellular basket as a % of GNI p.c.	1,4	0,6	0,3	1,1	0,5

Source: ITU

ICT skills

This sub-index seeks to capture capabilities or skills that are important for ICTs. It includes three indicators, namely: individuals with basic skills, standard skills and advanced skills. When compared to Brazil and Russia, South Africa has lower basic and standard skills. However, the percentage of individuals with advanced skills is higher compared to both countries. India and China were not ranked.

Table 2.28: Comparison of ICT skills level among BRICS countries

Skills level	South Africa	Brazil	Russia
	% of population		
Individuals with basic skills	15	21	41
Individuals with standard skills	10	12	14
Individuals with advanced skills	5	2	1

Source: ITU

3. SCIENCE, TECHNOLOGY AND INNOVATION FLOWS AND LINKAGES

In many countries, STI flows and linkages are at the core of a vibrant and high-performing innovation system. This chapter covers indicators such as research collaborations between South Africa and other countries as well as intra-sectoral and international mobility of South African doctoral graduates.

3.1. Research collaborations

It is standard practice in bibliometric analyses to define "research collaboration" between researchers (as well as research centres, institutions and countries) in terms of the co-authorship relations between contributing authors on scientific papers. However, it is also widely acknowledged that this indicator is merely a partial indicator of a much more complex construct of research collaboration. It does not capture other dimensions of research collaboration, such as joint proposal writing, joint funding, joint mentoring of young scholars, etc. But because of the standardised nature of bibliometric databases such as the Web of Science and Scopus, the relevant meta-data on co-authorships and affiliations is readily available to allow for the kind of analyses reported on here.

Figure 3.1 provides the trend in research (publication) collaboration between South African-authored publications in the CAWeb of Science and authors from other countries and regions in the world. Four categories of research collaborations that are shown are: (1) no collaboration or single-authored papers; (2) national collaboration (all the authors are from South Africa); (3) collaboration with Africa only (at least one author from an African country listed on the paper); and (4) collaboration with countries outside of Africa.

The trends in **Figure 3.1** are not surprising. Across all fields, there is a continuing decline in single-authored papers, from nearly 20% in 2000 to 10% in 2021. Further disaggregation by scientific field (**Annexure A)** shows that most of these papers are found in subjects such as philosophy, history and mathematics. A percentage share of national collaboration has similarly decreased.

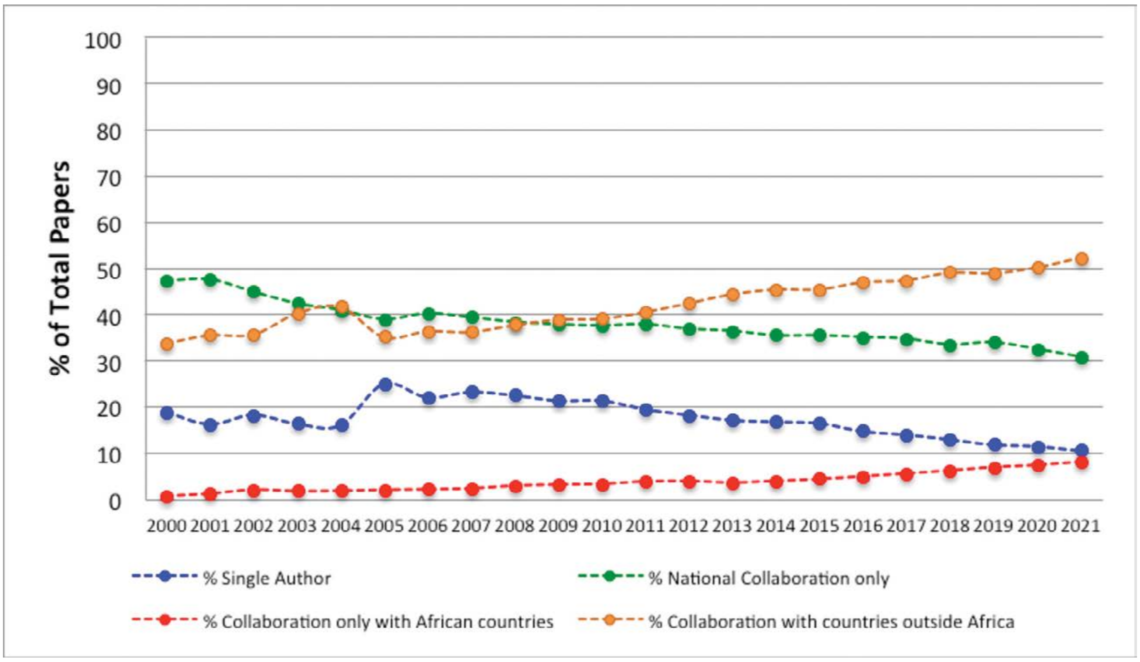


Figure 3.1: Trends in research collaboration (4 categories of co-authorship)
Source: CAWeb of Science

In **Figure 3.3**, the collaborations with Africa and countries outside of Africa are grouped into "foreign collaboration" to make the trends clearer. Foreign or international collaboration increased, from constituting one third of all scientific papers in 2000 to more than 60% in 2021.

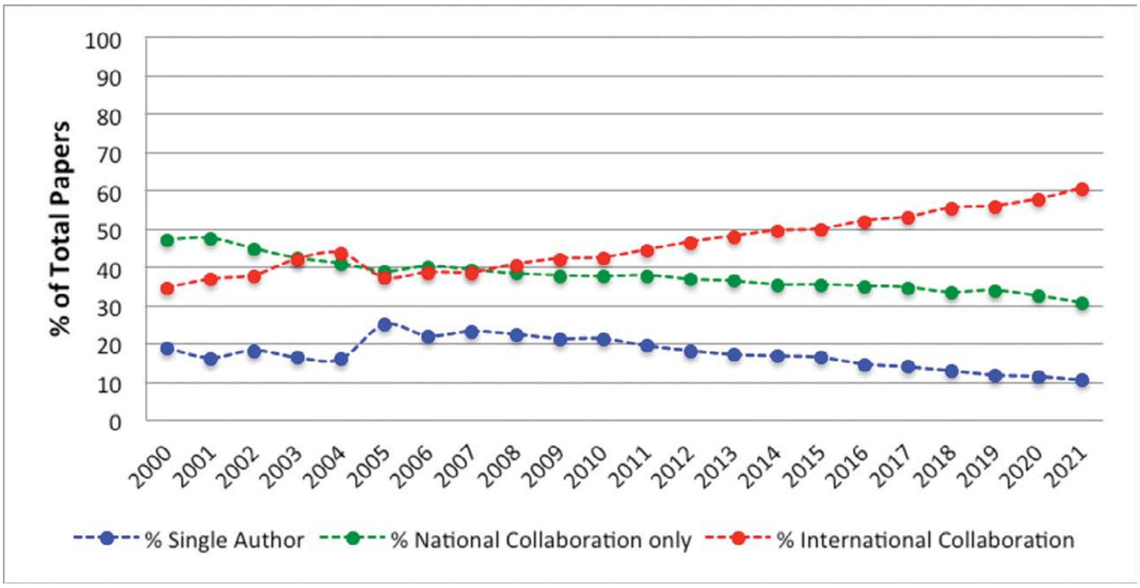


Figure 3.2: Trends in research collaboration (3 categories of co-authorship)
Source: CAWeb of Science

This increase has occurred with declines in both single-authored and nationally collaborative papers. It is worth emphasising that these trends summarise collaborative authorship in all scientific fields. In some fields, such as health sciences, astronomy and high-energy physics, foreign collaboration now typically comprises more than 90%. A more detailed breakdown by scientific field will show the large differences across disciplines.

Figure 3.3 and **Figure 3.4** visualise the changes in research collaboration patterns for two different periods. A comparison between the two maps shows how South African scientists have increased their collaborations with the USA, Germany, the UK and Australia (dark brown), and BRICS countries, Canada, and several European countries (dark red). With the exception of increased collaboration with Egypt, Nigeria and some east and southern African countries, collaboration with African countries remains low.

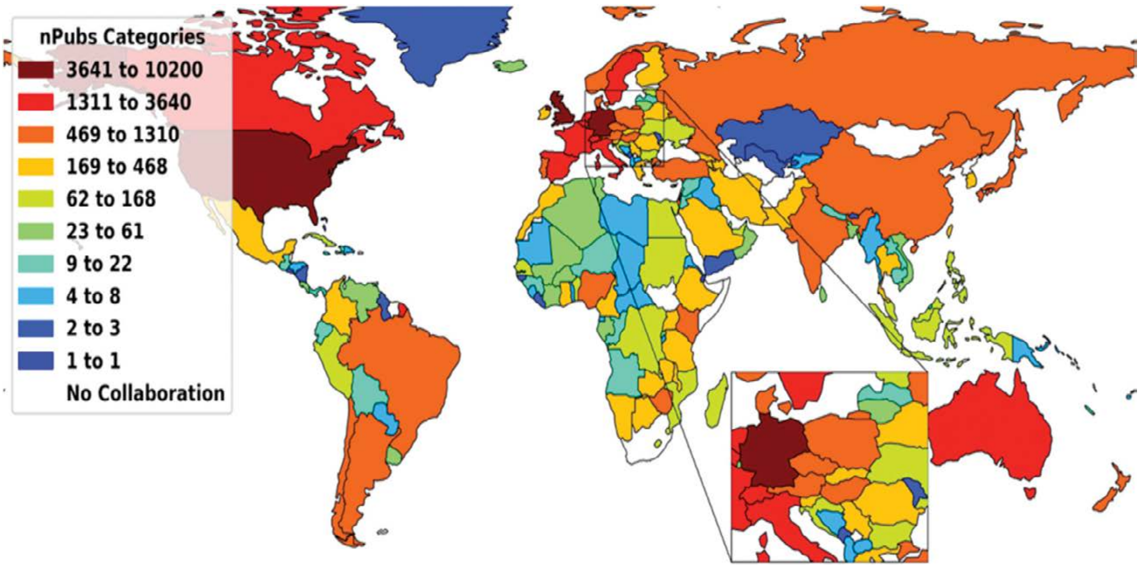


Figure 3.3: Comparative collaboration intensity between South Africa and other countries between 2000 and 2007
Source: CREST, Stellenbosch University

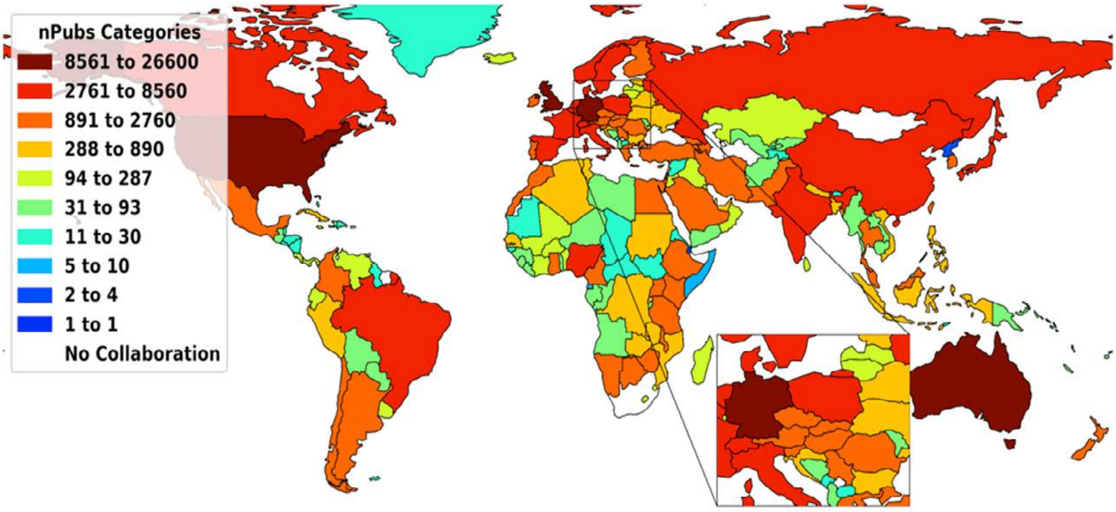


Figure 3.4: Comparative collaboration intensity between South Africa and other countries between 2013 and 2020
Source: CAWeb of Science

3.2. Mobility of doctoral graduates

Tracking the destination of doctoral graduates after completion of their studies is crucial to understand where the country needs more highly skilled labour for science and scholarship. There is currently no such study done on an annual basis, as it requires a significant investment in building the required database to track individual doctoral graduates (approximately 3 500 individuals) every year. However, in 2019 the Centre for Research on Evaluation, Science and Technology (CREST) conducted such a study on behalf of the DSI, which was project managed by the Water Research Commission. This study tracks two very important indicators of the mobility of doctoral graduates: the flows between different sectors of employment and the flows of graduates between countries and regions.

3.2.1. Intersectoral mobility

Figure 3.5 illustrates the differences between the graduates' sectors of employment at the time of the research and their sector of employment at the time of their doctoral studies.

The data shows that 86,3% (n = 2 185) of doctoral holders who were employed in the higher education sector during their doctoral studies were still employed in the higher education sector at the time of the survey (**see Table 3.1**).

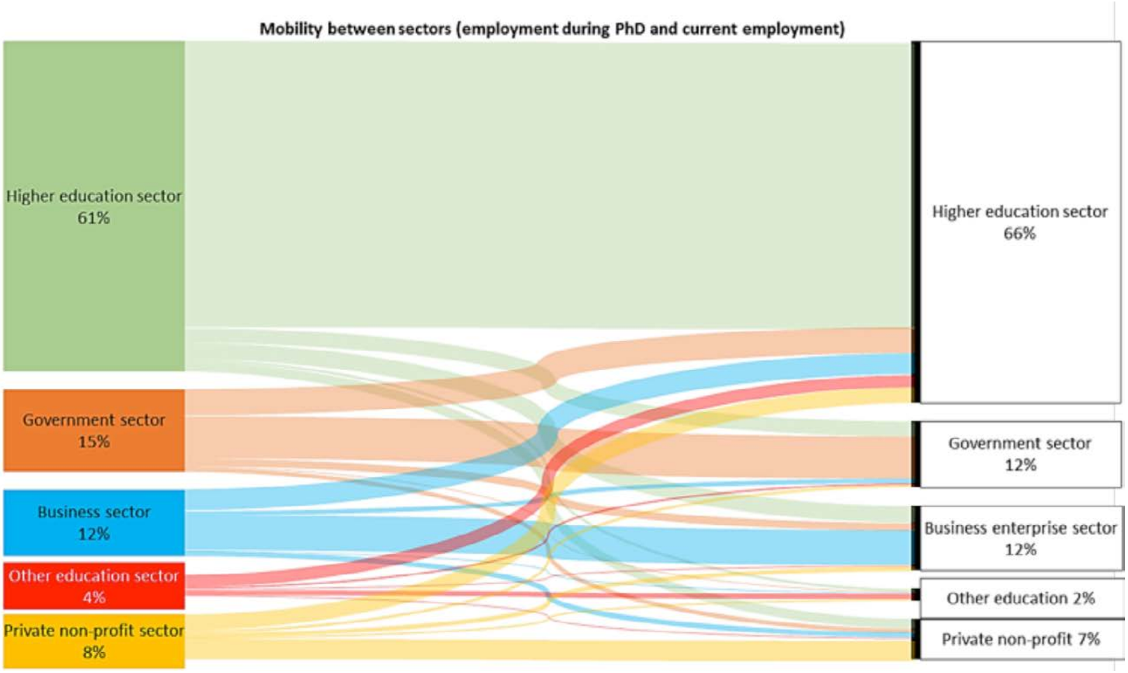


Figure 3.5: Intersectoral mobility of doctoral graduates in South Africa
Source: CREST, Stellenbosch University

In terms of outward mobility from the higher education sector, small percentages moved to the business sector (5,1%), government/public sector (4%), and the non-profit sector (2,9%). However, these "losses" were offset by gains both from the public sector (which includes science councils) and business. The result is a net gain for the higher education sector, where 66% of graduates are currently employed in the sector compared to 61% of graduates who were employed in the sector during their doctoral studies.

Table 3.1: Mobility between sectors of employment (from time of doing doctoral studies to current employment)

Sector of employment during PhD	Higher education		Government/ public		Business enterprise		Other education		Private non-profit	
	Number	%	Number	%	Number	%	Number	%	Number	%
Higher education	2 185	86,3%	113	4,0%	129	5,1%	20	0,8%	74	2,9%
Government/ public	199	33,5%	325	54,7%	62	10,4%	6	1,0%	35	5,9%
Business	162	35,0%	36	7,8%	268	57,9%	8	1,7%	37	8,0%
Other education	94	54,0%	12	6,9%	9	5,2%	43	24,7%	8	4,6%
Private non-profit	122	39,0%	21	6,7%	30	9,6%	13	4,2%	153	48,9%

Source: CREST, Stellenbosch University

The government/public sector recorded an overall net loss, mostly through migration of staff to universities. The data shows larger shifts within the government/public sector (which includes the science councils), where more than half of graduates (54,7%) who were previously employed in the government sector during their doctoral studies remained in the sector. In terms of outward mobility from the government sector, a third (33,5%) moved to the higher education sector, followed by 10,4% who went to the business sectors.

Looking at the third-largest sector of employment of doctoral graduates – the business or private enterprise sector – the majority of graduates (57,9%) remained in the sector. More than a third (35%) accepted a position in the higher education sector and near equal percentages (8%) moved to government or went into the private non-profit sector. These results are indicative of a fairly "stable" system with minimal inter-sectoral mobility of doctoral holders in South Africa.

3.2.2. International mobility

Figure 3.6 illustrates doctoral graduates' geographic mobility within the first year after completing their doctoral studies as disaggregated by their nationality at the time of pursuing their doctoral studies.

Data show that most South African nationals remained in South Africa after completion of their studies. A relatively small percentage (6%) pursued opportunities elsewhere in the world. The second-largest group (26%) of graduates was doctoral students from the rest of Africa. The majority of these returned to their home country, but nearly one in three remained in South Africa after graduation. A small percentage pursued opportunities elsewhere in the world. Of the total sample of doctoral graduates surveyed between 2000 and 2018, 6% were students from outside Africa and approximately half of them remained in South Africa, while a third returned to their home country after graduation.

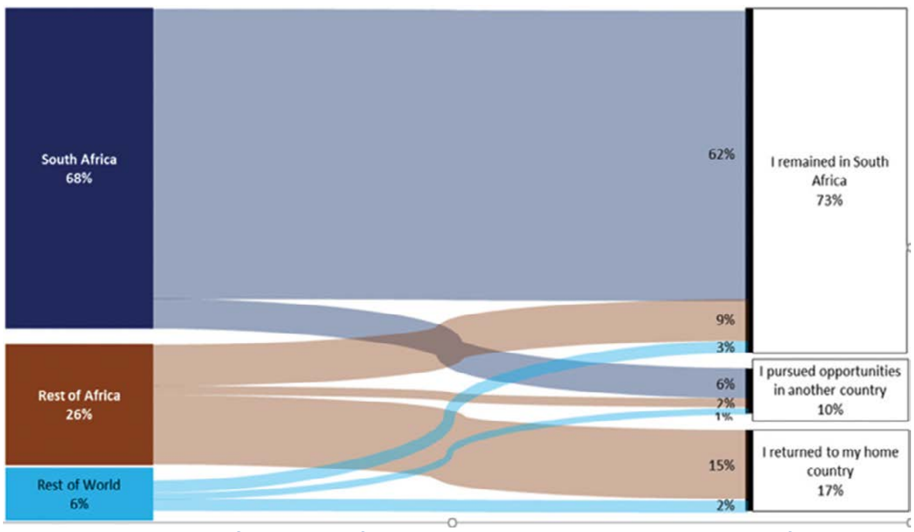


Figure 3.6: Geographic mobility within first year of obtaining doctorate by nationality of graduates. Source: CREST, Stellenbosch University

Figure 3.7 illustrates the movement of South African-born graduates between the first year after completing their doctoral studies and the time of the study. The data shows that the majority of respondents who remained in South Africa after completing their studies were still employed in South Africa at the time of the survey. In terms of outward mobility of South African graduates, 7% who initially remained in South Africa after completing their doctoral studies were, at the time of the survey, employed outside of South Africa. One percent (n = 31) were employed in an African country, while 6% (n = 211) held employment in a country outside the African continent. In terms of South African graduates who left South Africa after completion of their doctorate degrees (n = 352), 10 respondents were currently employed in Africa while the majority were employed elsewhere in the world. In total this constitutes 7% of the total sample.

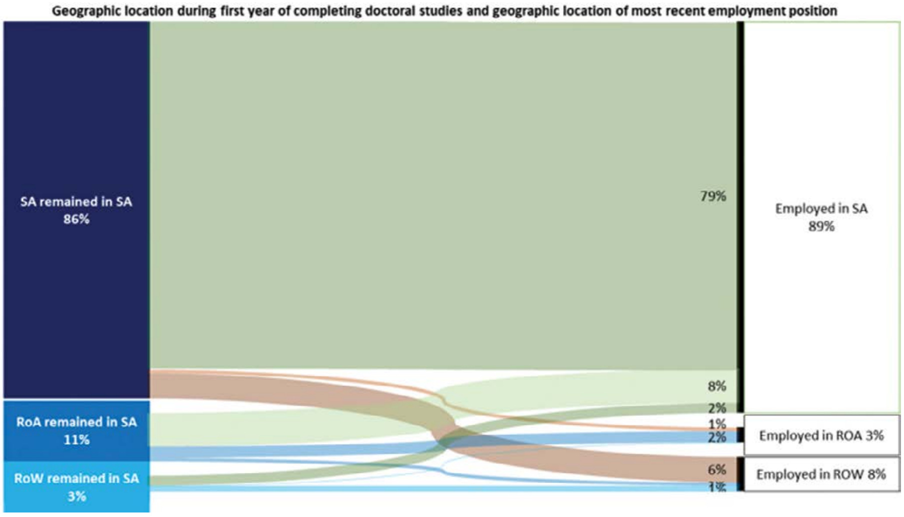


Figure 3.7: Geographic mobility of South African graduates within first year of obtaining doctorate.
Source: CREST, Stellenbosch University

In estimating the geographic mobility of doctoral holders, research shows that the vast majority of South African nationals (90%) remained in South Africa within the first year of completing their doctoral studies. Nearly 60% of graduates from African countries returned home within the first year of completing their studies, while 9% of graduates remained in South Africa. One out of five African graduates (ROA) considered the socio-political context in their home countries as motivations for remaining in South Africa on completion of their doctoral studies. The study also showed that graduates in STEM fields have greater outbound mobility compared to graduates in the social sciences, health sciences, and arts. Overall, and contrary to popular opinion, there is little evidence of a brain drain of South African doctoral graduates. There is, in fact, evidence of a net brain gain for South Africa of doctoral students who came from other African countries to study at South African universities.

4. SCIENCE, TECHNOLOGY AND INNOVATION OUTPUTS

The new framework adopted for this report makes use of the following STI outputs: graduates, scientific publications and technology. Technology in this report focuses on patents as well as plant breeders' rights (PBRs).

4.1. Graduate outputs

The goal of increasing the numbers of graduates in science, engineering and technology (SET) has been stated and repeated in multiple national policies documents post-1994. The 2019 White Paper on STI states that the country does not produce sufficient skills in SET for the economy. Despite various initiatives over the years to increase the output of SET graduates, Figure 5.1 shows that the percentage of SET graduates as a proportion of all graduates has remained unchanged over the past 12 years.

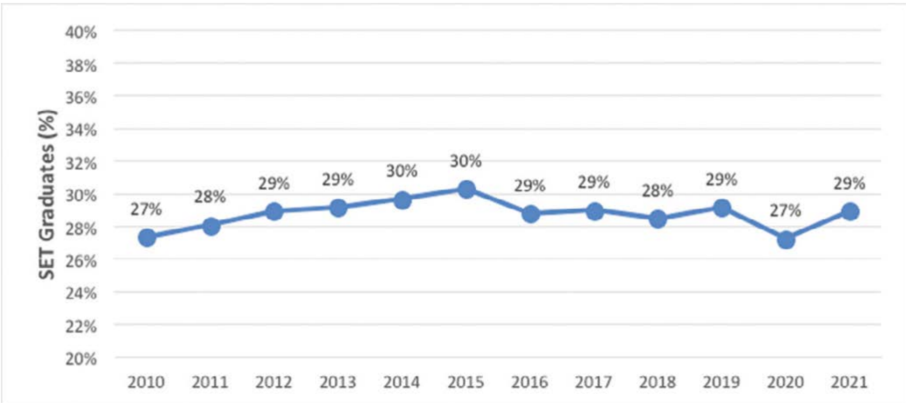


Figure 4.1: SET graduates as a percentage of all graduates in South African public universities
Source: CREST, Stellenbosch University

Figure 4.2 focuses on the percentage of doctoral graduates in SET. The trend is the same, with equal percentages of SET and non-SET students completing their doctoral studies over the same period.

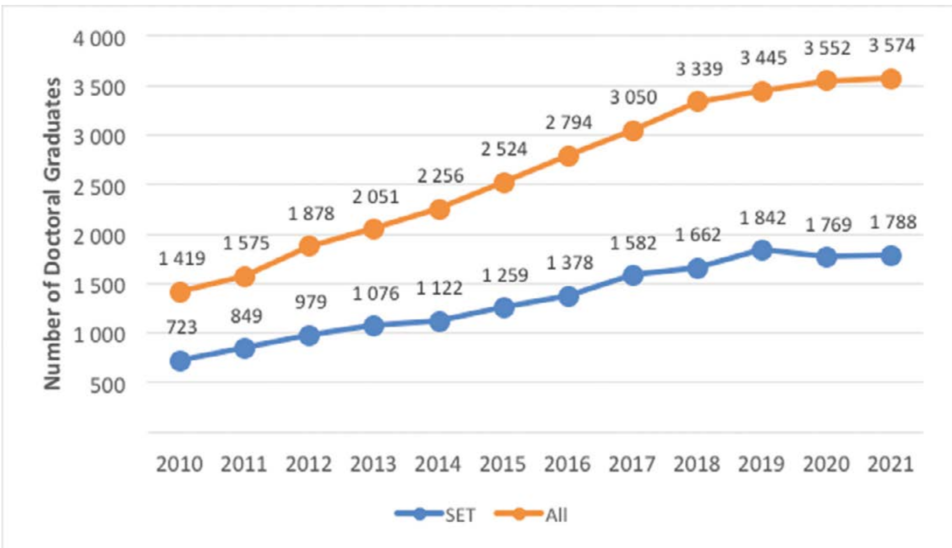


Figure 4.2: Doctoral graduates in SET by year
Source: CREST, Stellenbosch University

A positive trend in doctoral graduates in STEM fields is an increase in the numbers of female graduates. **Figure 4.3** shows that, since 2015, the relative percentage of female graduates in the STEM fields surpassed those of male graduates.

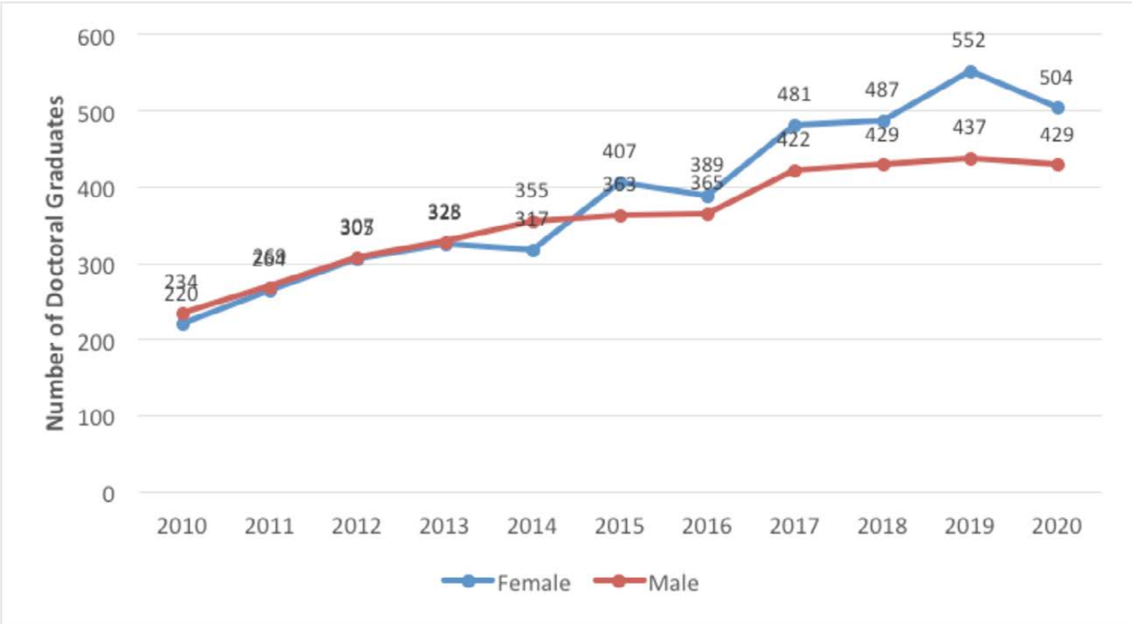


Figure 4.3: Doctoral graduates in STEM by gender (South African only) per year
Source: CREST, Stellenbosch University

Another positive development in the same domain has been the increase in number of black doctoral graduates in STEM fields. From constituting about one third of all doctoral graduates in 2010, the share of black doctoral students in STEM fields increased to 44% in 2020 (**see Table 4.1**).

Table 4.1: Doctoral graduates in STEM by race (South African only) per year

	African		Coloured		Indian/Asian		White		Total
	N	%	N	%	N	%	N	%	
2010	79	17%	29	6%	38	8%	307	68%	453
2011	85	16%	32	6%	55	10%	358	68%	530
2012	126	21%	38	6%	54	9%	393	64%	611
2013	142	22%	45	7%	59	9%	405	62%	651
2014	175	26%	43	6%	58	9%	393	59%	669
2015	190	25%	51	7%	91	12%	432	57%	764
2016	214	28%	47	6%	97	13%	394	52%	752
2017	273	31%	54	6%	84	9%	484	54%	895
2018	326	36%	49	5%	97	11%	436	48%	908
2019	362	37%	61	6%	77	8%	483	49%	983
2020	358	39%	45	5%	88	10%	433	47%	924
Total	**2 330**	**29%**	**494**	**6%**	**798**	**10%**	**4 518**	**56%**	**8 140**

Source: CREST, Stellenbosch University

Table 4.2 breaks down the doctoral graduates in STEM fields by country of origin (recoded as region) of students. The contribution of doctoral students from outside Africa (ROW) has increased over the past 11 years, but the absolute numbers remain small.

Table 4.2: Doctoral graduates in STEM by region per year

	South Africa		ROA		ROW		Total
	N	%	N	%	N	%	
2010	454	64%	204	29%	55	8%	713
2011	533	64%	241	29%	58	7%	832
2012	612	64%	295	31%	52	5%	959
2013	653	61%	352	33%	68	6%	1 073
2014	672	60%	373	33%	71	6%	1 116
2015	770	61%	415	33%	71	6%	1 256
2016	754	55%	525	38%	91	7%	1 370
2017	903	58%	575	37%	86	5%	1 564
2018	916	56%	615	38%	102	6%	1 633
2019	989	55%	709	39%	107	6%	1 805
2020	933	54%	687	40%	101	6%	1 721
Total	**8 189**	**58%**	**4991**	**36%**	**862**	**6%**	**14 042**

Source: CREST, Stellenbosch University

The largest increase is seen in doctoral students from African countries outside South Africa (ROA), especially up to 2019. Similar rates of increases are evident as far as South African-born students are concerned. However, a decline in all numbers since 2019 is a concern.

4.2. Scientific output (publications)

Discussions of scientific publications produced by South African authors must distinguish between an analysis of (1) publications produced by a South African scientist or scholar as reflected in an international bibliometric database such as the CAWeb of Science or Scopus; and (2) publications of South African academics that qualify for subsidies under the DHET Publication Policy Framework.

The inclusion of the latter is necessitated by two facts: first, because the university sector produces around 85% of all scientific publications in the country; and second, because publications by university academics are published not only in international journals (such as Scopus or Web of Science), but also in locally published journals that are accredited for subsidy-earning purposes by the DHET. The latter constitutes a significant proportion and excluding them introduces a significant scientific field bias (against the humanities and social sciences). In this section, therefore, the trends for these two perspectives are presented under two separate headings.

South Africa's scientific publications in the Web of Science

Figure 4.4 shows that South Africa has managed to maintain its strong annual growth in scientific articles: an increase of the absolute numbers from 3 693 in 2000 to 27 052 in 2021. However, despite this sustained increase in publications, the country's world share seems to have peaked at around 1% over the past five years. This means that other countries in the world (most notably, countries such as China and India) have increased their output at an even higher rate. Significantly, Clarivate Analytics added the Emerging Sources Citation Index to its standard set of citation indexes in 2015 in order to improve its coverage of developing countries. South Africa has benefitted from this decision, as the continued increase in the country's publication numbers since 2015 has been mainly driven by the inclusion of more than 40 South African journals in the Web of Science.

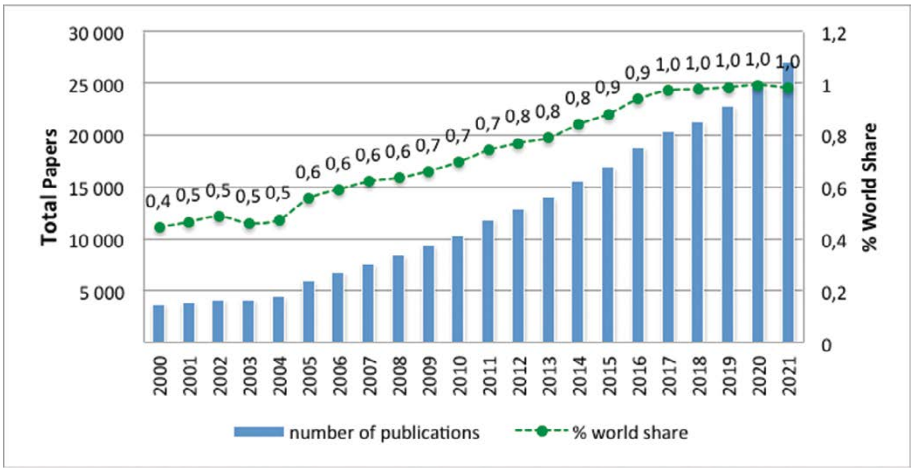


Figure 4.4: Number of articles and reviews (full-paper counting) and world share
Source: CAWeb of Science

The data presented in **Figure 4.4** is based on full paper counting at the country level. This means that, irrespective of the number of countries listed in the address field of a scientific paper, each country is counted only once. However, when one applies fractional counting at the country level to the same dataset, **Figure 4.5** shows that the number of publication units (fractionalised) is lower per year and that South Africa's share of the world is stable but decreasing to around 0,6% in 2021.

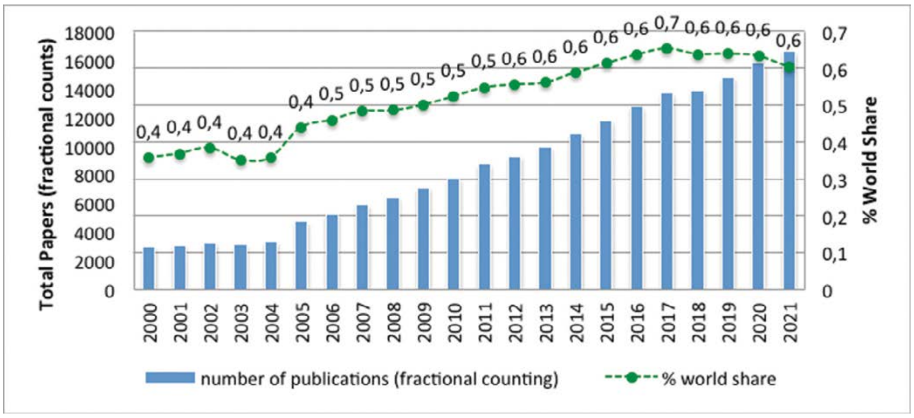


Figure 4.5: Number of articles and reviews (fractional counting) and world share
Source: CAWeb of Science

A major driver of these trends is South Africa's participation in very large international scientific programmes such as the European Organization for Nuclear Research and Global Health, where large numbers of authors co-produce a paper and the number of South African authors is proportionally smaller when compared to the numbers of authors from larger science systems in the world.

Figure 4.6 presents South Africa's "ranking" in terms of the number of scientific publications produced annually. South Africa obtained its best ranking (24th in the world) in 2016. In 2021, the country was ranked 30th in the world based on absolute output.

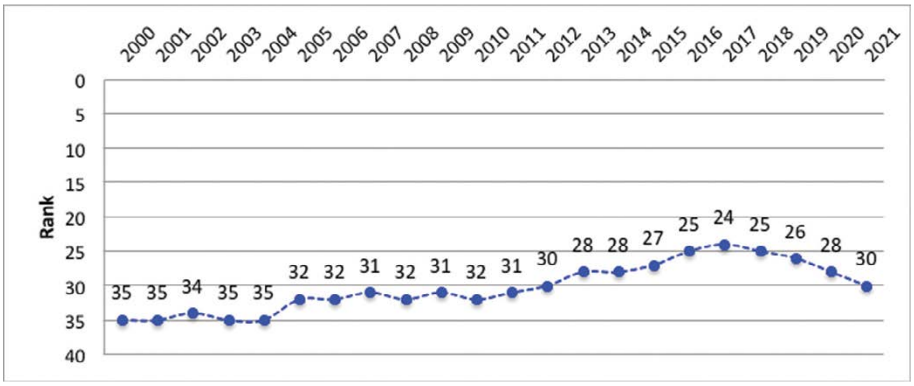


Figure 4.6: World rank according to absolute number of articles and review articles by year
Source: CREST, Stellenbosch University

Table 4.3 shows how South Africa's output compares with the 29 countries that rank above it in 2021. South Africa now occupies the second-highest position of all African countries behind Egypt who published 5 000 more articles than South Africa in 2021.

The absolute numbers reported in the previous figures do not normalise for any appropriate system-related characteristic of the South African system. Given the large differences between countries it has become commonplace to report on the number of scientific articles per million of the population.

Table 4.3: Number of articles and review articles by country in descending order in 2021

Country	Number of articles and review articles
China	650 118
United States	584 018
United Kingdom	195 789
Germany	161 889
India	154 186
Italy	119 624
Japan	113 880
Canada	107 986
Australia	106 451
Spain	103 589
France	100 643
Korea, Republic Of	88 304

Country	Number of articles and review articles
Brazil	84 797
Russian Federation	70 644
Islamic Republic of Iran	66 367
Turkey	62 549
Netherlands	61 167
Poland	50 907
Switzerland	47 084
Saudi Arabia	45 516
Sweden	42 846
Taiwan, Province of China	38 789
Belgium	34 320
Pakistan	33 589
Egypt	32 283
Denmark	29 392
Portugal	27 388
Malaysia	27 218
Mexico	27 124
South Africa	27 052

Source: CREST, Stellenbosch University

Figure 4.7 shows that the science system has continued to become more productive when the number of publications is divided by millions of the population. The increase in this value over the past 21 years is positive and shows that South African scientists, despite financial and other constraints, continue to be increasingly productive.

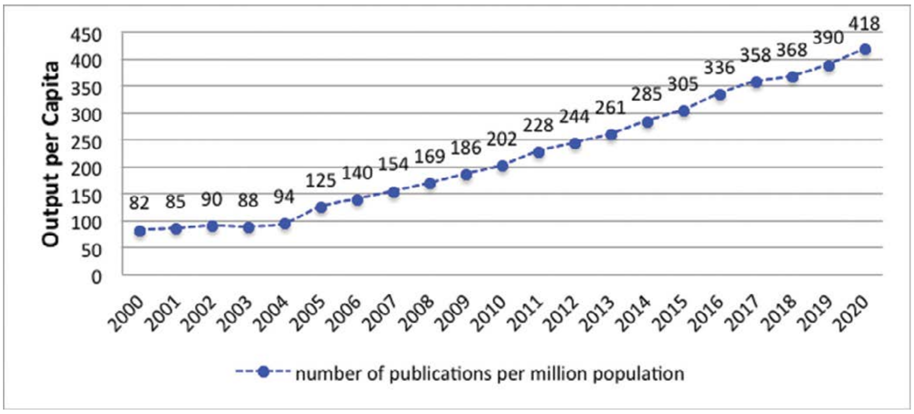
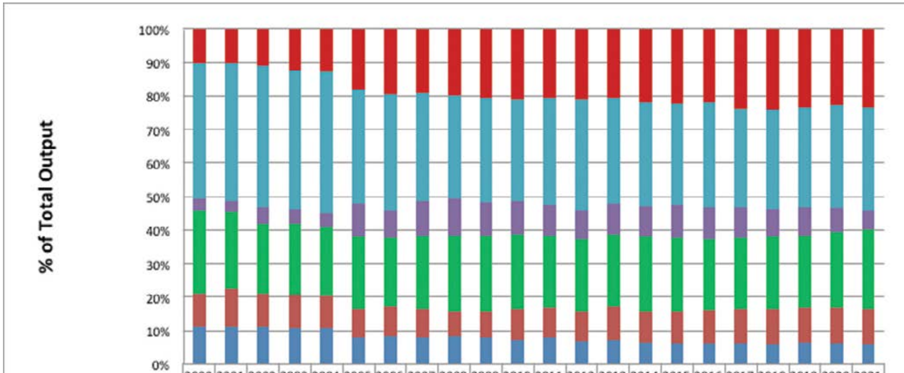


Figure 4.7: South African publication output per million of population
Source: CREST, Stellenbosch University

Figure 4.8 presents the “shape of scientific knowledge production” in a system. The articles and review articles listed in the previous tables and graphs are assigned to six main science domains based on the journals, hence subject categories in which they are published. However, given the small degree of overlap between some of the categories, the sum of publications in each year exceeds the numbers reported in earlier graphs.

Figure 4.8 reveals how “stable” the disciplinary breakdown of articles is in a science system. Over the reporting period of 22 years, there has been a decline in the relative contribution of the agricultural sciences, with a concomitant increase in the relative share of the social sciences. The context for this trend is that, over this period, the Web of Science has increased its indexing of South African journals by a factor of more than three and the majority of additional journals are from the humanities and social sciences. Because of the improved coverage of South African journals in the social sciences and humanities, the shares of these two science domains have increased proportionally to the other domains. The larger fields have also increased their output substantially: the number of publications in the health sciences increased more than seven-fold over these periods and the number of publications in natural sciences increased from 1 677 in 2000 to 9 439 in 2021.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Social sciences	418	461	530	594	655	1202	1490	1622	1886	2187	2466	2761	3010	3177	3802	4183	4693	5477	5742	6031	6309	7134
Natural sciences	1677	1828	2031	2021	2179	2282	2636	2754	2909	3356	3570	4265	4731	4934	5405	5670	6626	6777	7176	7646	8586	9439
Humanities and arts	148	146	243	209	217	680	625	876	1040	1052	1174	1221	1205	1433	1583	1836	1973	2131	1950	2110	1930	1744
Health sciences	1012	1025	1014	1024	1061	1436	1558	1885	2135	2431	2617	2886	3095	3330	3912	4121	4559	4863	5236	5561	6301	7214
Engineering	421	502	474	486	492	561	684	741	703	821	1068	1170	1277	1539	1588	1758	2109	2387	2491	2703	2992	3273
Agricultural sciences	453	494	541	516	556	541	619	669	776	856	872	1076	998	1153	1141	1186	1308	1429	1432	1643	1712	1748

Figure 4.8: Articles and review articles by main science domain and year
Source: CREST, Stellenbosch University

One of the standard indicators used in bibliometric studies to measure whether a country (or region or institution) is strong in a particular field is the specialisation or activity index. The term “activity” does not capture the notion of strength adequately. The term “specialisation” is equally problematic as it is more often used in discussions about specialisation within disciplines.

Because this index measures the “relative” strength of a particular field or discipline compared to others, we refer to as the “relative field strength (RFS) index”. An RFS value of 1 in a field or discipline implies that this entity (country or region) has a world share for that field similar to its share in all fields combined. This is a “neutral” situation, meaning there is no relative strength in that particular field. When the RFS index is greater than 1, the country is said to be strong in that field, at the expense of some other fields or disciplines for which the index is less than 1.

The results of analysis of the South African science system are presented in **Figure 4.9**, which compares the values on the RFS-index for two periods (2005 to 2012 and 2013 to 2020). The important findings show above-average activity and relative strength of South Africa in the agricultural science, social sciences and humanities. South African scientists are not well represented in engineering, whereas the outputs in the health and natural sciences are more or less proportionate to the world averages in these fields.

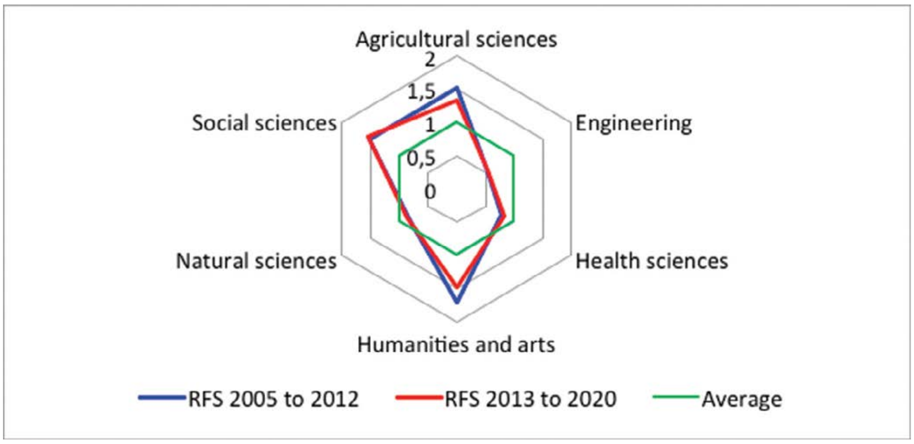


Figure 4.9: Comparative relative field strength (relative activity index)
Source: CREST, Stellenbosch University

Publications by South African universities

Figure 4.10 presents the overall trends of all publication units (subsidy-earning units) by the 26 universities in the country from 2005 to 2021. The data show a continued increase in the annual output in all publication categories.

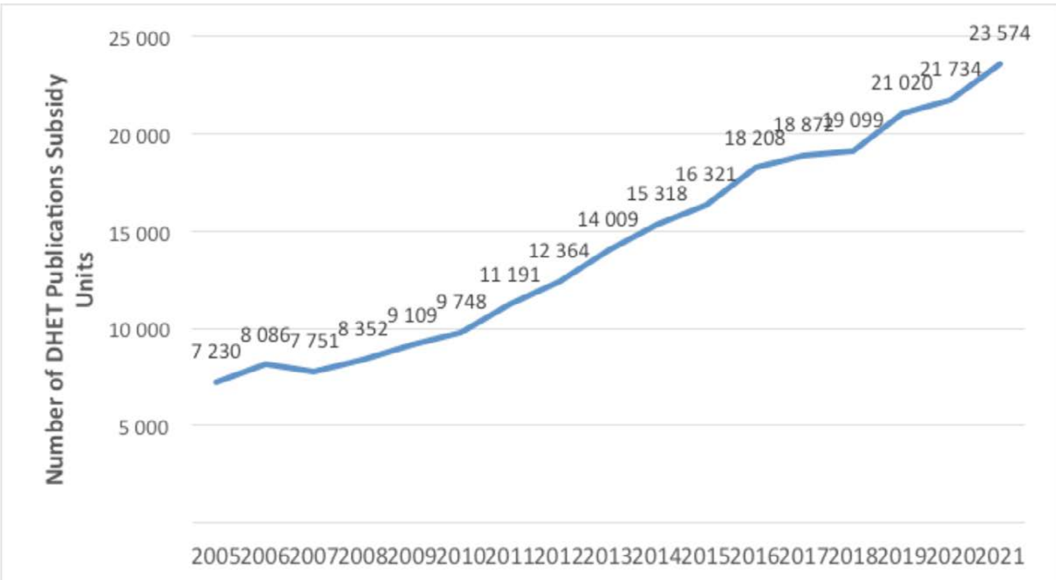


Figure 4.10: Trends in output of subsidy-units research publications by universities
Source: CREST, Stellenbosch University

This shows that, at least as far as the initial goal of the DHET, which is to increase the quantity or volume of output through this system, the results have been positive.

The next two figures present the trends on two "transformation" variables: gender and race of author. The results **(Figure 4.11)** clearly show that female authors have substantially increased their contribution to university publications over the reporting period (by 10 percentage points, from 31% in 2005 to nearly 42% in 2021).

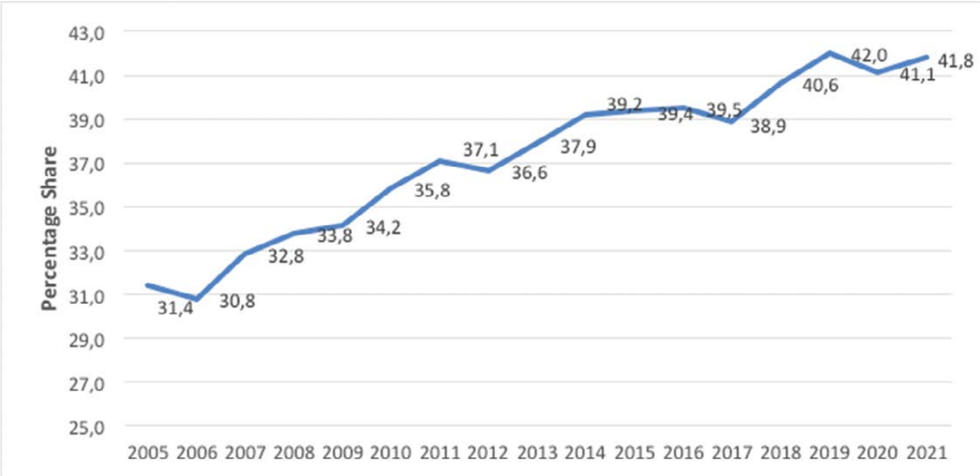


Figure 4.11: Trends in percentage of female-authored publications (South African-born authors only)
Source: CREST, Stellenbosch University

The trend in the publications by South-African black academics shows that post-doctoral fellows and staff had a nearly three-fold increase in contributions over the 17-year period (**see Figure 4.12**).

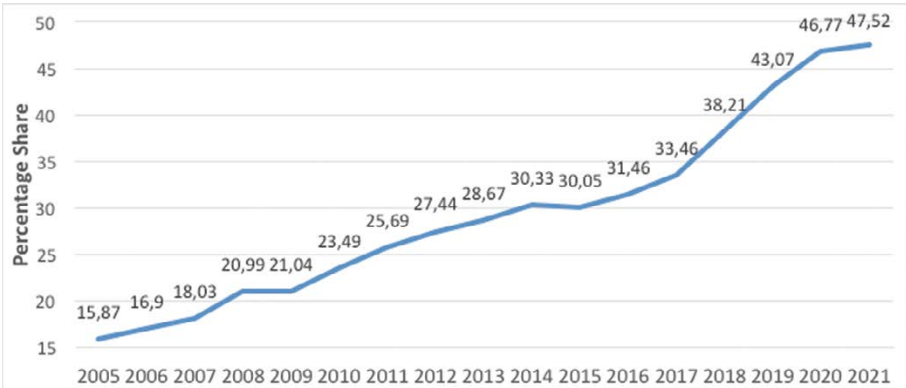
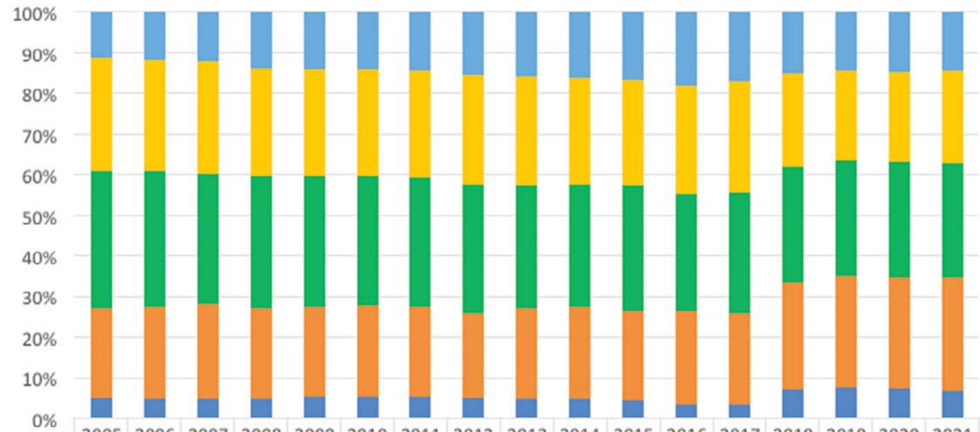


Figure 4.12: Trends in percentage of black-authored[4] publications
Source: CREST, Stellenbosch University

The results presented in **Figure 4.13** reveal interesting shifts in the age profile of South African university authors under the DHET-subsidy framework. Both the youngest and oldest age categories have shown an increase in authorships over time. The contribution of authors aged 60 and older increased from 11% in 2005 to nearly 15% in 2021. This would reflect a general trend at most universities to retain some of their retiring staff and, in fact, reward those who retire to keep on publishing and earning subsidies for their universities. The increase in the contributions from those younger than 40 (often referred to as early-career academics) is positive: from contributing 27% in 2005 to 35% in 2021. However, this increase is not only due to the appointment of more permanent younger staff, but also because of the increasing contributions that postgraduate students and post-doctoral fellows are making to the publication outputs of most universities.

4 “Black” here includes black African, coloured, Indian/Asian South African nationals only.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
60+	11,13	11,74	11,99	13,81	14,23	14,15	14,59	15,3	15,91	15,93	16,64	18,04	17,15	15,15	14,42	14,64	14,58
50-59	27,96	27,45	27,84	26,5	26,23	26,18	26	27,12	26,74	26,36	25,86	26,7	27,19	23,04	22,16	22,19	22,46
40-49	33,86	33,49	32,14	32,38	32,09	31,86	32,1	31,62	30,05	30,37	31,07	28,87	29,76	28,54	28,23	28,39	28,18
30-39	21,93	22,45	23,12	22,46	21,99	22,27	21,96	20,76	22,41	22,64	22,03	22,88	22,44	26,04	27,34	27,21	28,03
<30	5,12	4,87	4,91	4,84	5,46	5,54	5,36	5,2	4,9	4,7	4,39	3,51	3,46	7,23	7,84	7,57	6,76

Figure 4.13: Trends in the age of South African publishing authors
Source: CREST, Stellenbosch University

4.3. Technology outputs

4.3.1. Patents

Patents granted in large markets that have extensive examination procedures are one index of a country's progress at the technology frontier. Patents at the United States Patent Office and the European Patent Office (EPO) are used most widely.

With respect to domestic patents, patents granted to South African residents have been on a downward trend over the decade. Patents granted to South African residents rose in 2019 (54%) but then declined (-55%). In 2021, patents granted to South African residents increased year-on-year 81%.

The number of patents granted to non-residents has shown no discernible trend over the past decade. As with patents granted to South African residents, there was a significant increase in 2019 as compared with the previous year (27%) and a sharp decline in 2020 (42%). In 2021, patents granted to non-residents increased year-on-year (76%).

The share of patents granted to South African residents has tended to decline over the decade. In 2020, only 9% of patents granted in South Africa were to South African residents. In 2021, the share of patents granted to South African residents increased marginally to 9,3%.

Table 4.4: Resident and foreign patent grants

	Resident	Non-resident	Total	Resident %
2011	567	4 729	5 296	10,7
2012	685	5 520	6 205	11,0
2013	474	4 282	4 756	10,0
2014	445	4 620	5 065	8,8
2015	453	4 046	4 509	10,0
2016	403	3 852	4 255	9,5
2017	595	4 940	5 535	10,7
2018	451	4 295	4 746	9,5
2019	694	5 468	6 162	11,3
2020	313	3 153	3 466	9,0
2021	565	5 542	3 466	9,3

Source: WIPO Statistical Country Profiles

The number of South African patents granted at the EPO has fluctuated over the decade. There was a significant increase in South African patents at the EPO in 2020 (14%).

In 2021, the number of South African patents granted at the EPO declined by 36% as compared with the previous year. The total number of patents granted for all countries at the EPO declined by 18,6% in 2021. The number of South African patents granted at the EPO in 2021 is well below the average for the decade.

Table 4.5: South African patent grants at the EPO

	Number of patent grants
2011	53
2012	65
2013	54
2014	50
2015	59
2016	70
2017	50
2018	73
2019	69
2020	80
2021	51

Source: EPO database

Table 4.6 lists the top South African patent applicants in terms of the Patent Cooperation Treaty (PCT) in 2021. Patent applications in 2021 were dominated by universities and several firms located in mining and mining-related activities.

Table 4.6: PCT top applicants

	2018	2019	2020	2021
Detnet South Africa Pty Ltd	6	1	11	7
University of Cape Town	11	18	7	7
Stellenbosch University	2	17	6	6
Innovative Mining Products	-	-	-	5
Poynting Antennas	-	-	-	5
Omnia Group Pty Ltd	-	-	-	4
Mintek	-	2	-	3
University of Pretoria Epiroc Holdings of South Africa Epiroc Holdings SA Pty Ltd	4	5	9	3
Nelson Mandela University	-	-	1	3
AECI Mining Limited	-	-	-	2

Source: WIPO statistics database

4.3.2. Technology balance of payments

South Africa's payments abroad for the use of IP have declined significantly since 2017. This decline reflects lower levels of investment as economic growth has slowed. In 2021, there was an increase over the previous year (21%). This followed two earlier years of decline (-12% in 2019 and -16,6% in 2020). Payments abroad for the use of IP in 2021 were significantly lower than they were in any year of the decade prior to 2018.

Receipts from the sale of South African IP increased in 2021 as compared to the previous year (6,6%). However, this followed significant decreases in the two previous years. Receipts from the sale of South African IP in 2021 are similar to what they were a decade ago.

Table 4.7: Charges for the use of intellectual property

	Payments ($ billion)	Receipts ($ 000)
2011	2,12	139 891
2012	2,02	135 297
2013	1,94	135 485
2014	1,73	136 803
2015	1,64	126 114
2016	1,83	139 258
2017	1,88	157 684
2018	1,54	182 504
2019	1,36	150 760
2020	1,20	126 359
2021	1,45	135 304

Source: World Bank "World Development Indicators"

Brazil, Argentina, and South Africa all saw declines in their receipts from the sale of their IP in the period 2018 - 2020. But, for both Brazil and Argentina, receipts in 2021 were significantly higher than in 2016. By contrast, for South Africa, receipts from the sale of IP were lower in 2021 than in 2016 (-3%).

Compared with all middle-income countries, South Africa's share of receipts has declined significantly and consistently: from 3,3% in 2016 to 0,8% in 2021.

Table 4.8: Charges for the use of intellectual property receipts (SA and selected countries)

	2016	2017	2018	2019	2020	2021
Current $US' 000						
Argentina	168 807	356 98	321 051	284 486	209 592	212 632
Brazil	650 834	642 57	825 475	641 114	634 292	705 262
South Africa	139 258	157 84	182 504	150 761	126 359	135 304
Current $US billion						
Middle income	4,17	8,67	10,14	11,18	13,61	17,25
South Africa share of middle income	3,3	1,8	1,8	1,4	0,9	0,8

Source: World Bank World Development Indicators

4.3.3. Plant Breeders' Rights

The annual trend in plant breeders' rights (PBRs) granted in South Africa are shown in **Figure 4.14**. After a period of stagnation during 2011 to 2020, the number of PBRs granted increased by more than 50% to reach an annual total of 319 in 2021. At the time of this report, only data from quarter 1 and 2 of 2022 were available. This year-to-date data shows that the annual number of PBRs granted in 2022 would at least match the 2021 level.

Figure 4.14: Trend of plant breeders' rights granted in South Africa
Source: DALRRD Plant Variety Journals

The South African market of plant varieties is dominated mainly by breeders from the USA, with a share of 32,2% and 31,0% in 2021 and 2022 respectively (see Figure 5.15). South Africa's share of the local PBRs was 20,7% and 16,6% respectively in 2021 and 2022. This shows domination of the local market by US organisations.

The other top grantees of PBRs in South Africa are developed countries from Europe and Oceania, as well as countries such as Israel, Argentina and Brazil. Most of the PBRs from Israel (36%) are from the Agricultural Research Organisation, a public research institute responsible for more than 75% of Israel agricultural research and innovation.

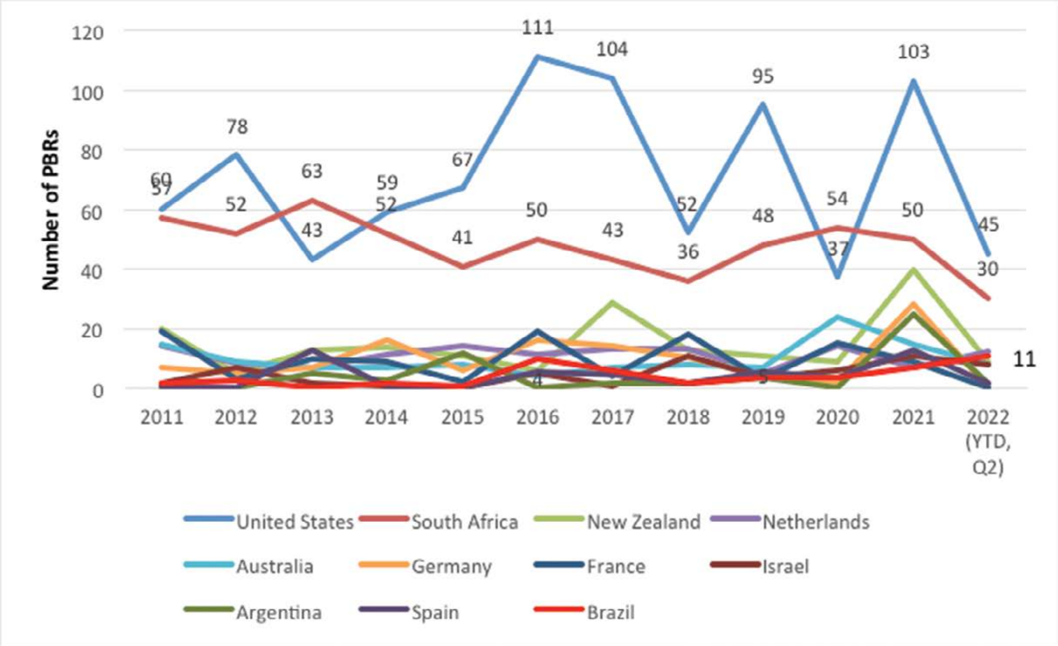


Figure 4.15: Trends of plant breeders' rights granted in South Africa to top countries.
Source: DALRRD Plant Variety Journals

As shown in **Figure 4.16**, most PBRs granted in South Africa are from the private sector (93% in 2021); although this sector experienced a decline in the first half of 2022 (74% share).

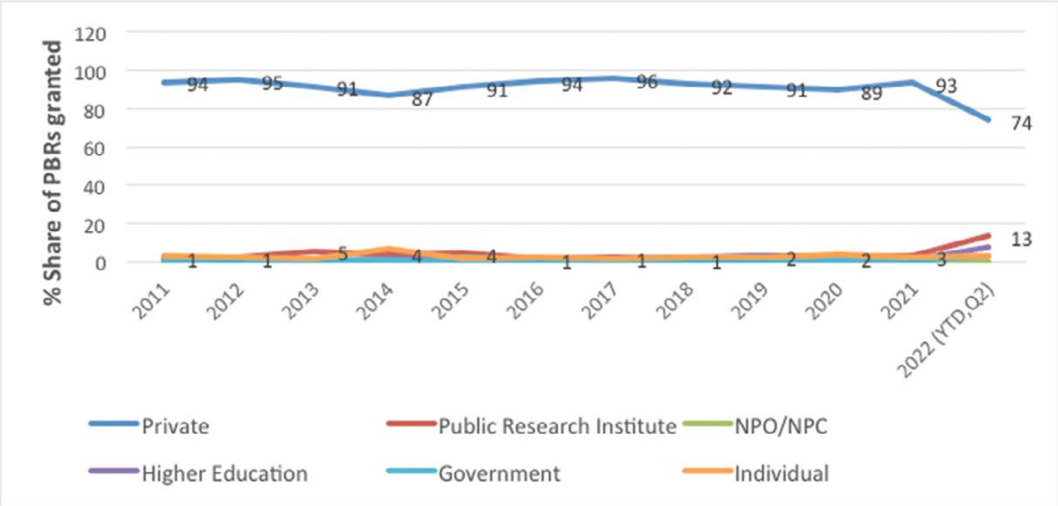


Figure 4.16: Distribution of South African-granted plants breeders' rights by sector
Source: DALRRD Plant Variety Journals

The PBR data reveals that, for developed countries, there is more participation of universities and public research institutes in the development of plant varieties. In South Africa, there is no university that has obtained PBRs in the past decade. The Agricultural Research Council (ARC) is starting to increase its PBRs granted, following a long period of decline. In mid-2022, five PBRs were granted to the ARC. During the period 2011 - 2022, the ARC was granted 40 PBRs. Therefore, about 12,5% of these PBRs were granted during the first two quarters of 2022 alone.

5. INNOVATION IMPACTS

The STI impacts in this chapter are assessed through indicators such as the citations in scientific publications as well as select economic and social impact indicators, namely, scientific impact, economic impact (gross value added in the manufacturing sector) and merchandise exports by technological intensity.

5.1. Scientific impact

The number of times a publication is cited is often used as a measurable proxy for quality or impact. While the strength of this proxy is debatable, citations are indicators of visibility and recognition. Citation practices differ vastly between scientific disciplines, so the number of citations received by publications across disciplines cannot be compared. A common indicator that overcomes this problem is the normalised citation score that is normalised for the scientific disciplines associated with a publication as well as the year it was published. This allows calculation of the mean normalised citation score (MNCS) of any set of publications, which can be used for comparison. An MNCS = 1 is commensurate with the average citation impact of a system or institution; an MNCS ≥ 1.2 is considered above average and MNCS ≤ 0.8 is considered below average.

Figure 5.1 shows the trend in the citation impact of South Africa's scientific publications as measured by the MNCS for the past 22 years. The overall picture is positive, with the citation impact of these publications in 2021 calculated at around 25% (1,26) higher than the average citation values for all world publications in the same fields.

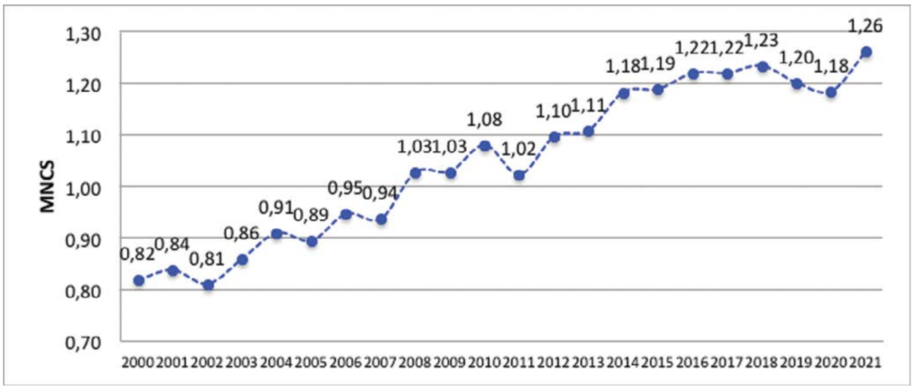


Figure 5.1: Trends in citation impact (MNCS: 2-year window) by year

Source: CREST, Stellenbosch University

In addition to the MNCS score as indicator of citation impact, the Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy (SciSTIP), at Stellenbosch University, also calculates three other related citation indicators originally developed by the Centre for Science and Technology Studies at the University of Leiden. These are the PP (top 1%), PP (top 5%) and the PP (top 10%) indicators. The PP (top 1%) indicators, as an example, measure the proportion of a country's publications that, compared with other publications in the particular field and in the same year, are in the top 1% most frequently cited. The same explanation applies to the PP (top 5%) and PP (top 10%). Because the citation density (relative citation rate) differs dramatically across scientific fields, we have calculated the values of these three indicators for the period up to 2021 for five high-level science domains. The results are presented in **Figures B1** to **B5** in **Annexure B.**

The results are generally positive, showing that South African-authored publications in most fields are well represented in the different percentile intervals. The trend over time is fairly consistent. As expected, the highest percentage of papers in the top 1% of most-cited papers is in the natural, health and engineering sciences.

5.2. Innovation for economic impact

The economic impacts outlined are for output, employment and exports.

5.2.1. Gross value added in the manufacturing sector.

Manufacturing output, measured by Gross Value Added (GVA), in 2021 increased by 4,5%. This followed a decline of 12% in 2020. Manufacturing GVA in 2021 was still lower than a decade ago.

MHT manufacturing GVA increased by 6,6% in 2021 and MHT excluding motor vehicles increased by 8,8%. This increase followed declining output in the previous four years. Over the decade, there has been a tendency for the shares of MHT and MHT excluding motor vehicles in manufacturing GVA to decline slowly, with a more pronounced decline from 2016. As a result, the share of GVA of both MHT and MHT excluding motor vehicles were lower in 2021 than they were a decade ago.

Table 5.1: Manufacturing, medium and high-technology manufacturing value added.

	Gross value added, rand million: constant 2015 prices										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Manufacturing	541 829	552 595	558 021	554 420	553 392	555 880	554 833	565 926	557 941	488 409	520 303
MHT	157 731	157 117	158 051	157 823	157 937	159 868	155 966	155 028	147 827	125 036	133 324
MHT less motor vehicles	138 059	136 750	137 025	136 458	136 014	138 376	134 715	131 941	124 611	108 555	117 981
MHT (% share)	29,11	28,43	28,32	28,47	28,54	28,76	28,11	27,39	26,50	25,60	25,62
MHT less motors (%)	25,48	24,75	24,56	24,61	24,58	24,89	24,28	23,31	22,33	22,23	22,68

Sources: Quantec & Stats SA

Regarding the different sectors within MHT, percentage shares of GVA have generally been stable over the last decade. Special-purpose machinery increased its share after 2016.

Table 5.2: Medium and high-technology sectors value added % share.

	% share of gross value added: constant 2015 prices										
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Basic chemicals	12,95	11,49	11,71	12,27	12,49	14,21	13,39	13,03	11,89	13,54	13,28
Other chemical products	20,10	19,72	20,31	20,40	20,39	20,68	19,87	18,45	16,81	18,91	18,55
General purpose machinery	12,13	12,31	11,26	10,38	9,41	9,13	9,75	9,95	10,66	10,89	11,19
Special purpose machinery	13,32	13,66	13,89	13,62	13,28	12,64	13,71	13,92	14,27	14,11	14,23
Household appliances	1,91	1,99	1,94	2,01	1,87	1,68	1,76	1,83	2,04	1,98	2,08
Office, accounting, computing machinery	0,88	0,87	0,87	0,91	0,84	0,74	0,77	0,78	0,86	0,78	0,78
Electric motors, generators, transformers	1,51	1,77	1,82	2,00	2,01	2,23	1,95	2,04	1,99	1,95	1,58
Electricity distribution and control apparatus	1,31	1,28	1,32	1,18	1,23	1,20	1,31	1,27	1,32	1,11	1,22
Insulated wire and cables	1,45	1,43	1,41	1,36	1,34	1,36	1,44	1,45	1,48	1,40	1,42
Other electrical equipment	3,00	3,03	3,44	3,31	3,82	3,59	3,14	3,10	3,31	3,69	3,66
Radio, television and communication apparatus	1,08	1,19	1,26	1,54	1,43	1,65	1,60	1,43	1,69	1,80	1,79
Professional equipment	3,03	3,10	3,08	3,29	3,25	3,30	3,73	3,74	3,58	3,73	3,74
Motor vehicles	12,47	12,96	13,30	13,54	13,88	13,44	13,63	14,89	15,70	13,18	11,51
Parts and accessories	10,75	10,61	10,04	9,82	10,23	9,81	9,17	9,50	9,09	8,44	10,42
Other transport equipment	4,11	4,59	4,33	4,38	4,52	4,33	4,80	4,61	5,30	4,51	4,56

The share of motor vehicles increased throughout much of the decade but has declined in the last two years. There are no MHT sectors which show significant and sustained increases in their relative share over the decade.

5.2.2. Merchandise exports by technological intensity

Manufacturing exports have been declining since 2016. There was a significant decline in manufacturing exports in 2020 (-14%). In 2021 manufacturing exports increased (11,7%) but remain well below the figure from 2016.

Table 5.3: Manufacturing exports, medium and high-technology exports, R million constant 2015 prices, and % shares

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Manufacturing	496 501	512 370	525 032	548 151	560 263	566 251	546 179	561 491	541 096	464 876	519 283
MHT	227 984	244 397	241 583	257 033	274 869	276 994	263 025	269 295	267 662	224 914	239 999
MHT excl. motor vehicles	169 482	178 078	179 470	185 485	183 654	188 577	179 218	180 514	182 222	172 967	183 371
MHT %	45,92	47,70	46,01	46,89	49,06	48,92	48,16	47,96	49,47	48,38	46,22
MHT excl. motor vehicles %	34,14	34,76	34,18	33,85	32,78	33,30	32,81	32,15	33,68	37,21	35,31

Sources: Quantec & Stats SA

MHT and MHT excluding motor vehicles exports follow the same trajectory as manufacturing exports: declining after 2016; a significant decline in 2020; a significant increase in 2021 (MHT 6,7%; MHT excluding motor vehicles 6%), but still leave exports below their 2016 level. As a share of manufacturing exports, MHT and MHT excluding motor vehicles are only marginally higher in 2021 than a decade ago.

Service exports

Service exports have trended lower since 2012. Service exports declined significantly in 2019 (-7%), followed by a major decline in 2020 (-46%). This was largely the result of reduced earnings from tourism as a consequence of the pandemic. In 2021, service exports increased by 5% but were little more than half of what they were at the beginning of the decade.

Table 5.4: South African exports total and service exports

BoP, current US$ billions		
	Total	Services
2011	126,94	17,48
2012	117,93	17,89
2013	113,64	17,12
2014	110,44	17,20
2015	96,35	15,56
2016	91,48	14,97
2017	104,17	16,53
2018	111,33	17,08
2019	105,99	15,90
2020	94,12	8,66
2021	130,88	9,11

Source: World Bank World Development Indicators

5.2.3. Composition of exports

The tables below show export values; the number of exporters; the number of products exported; the number of export destinations and the number of export transactions[5].

Table 5.5: Total exports characteristics (excluding gold)

	Number of exporters	Number of products	Number of destinations	Number of transactions
2010	32 928	4 247	218	862 463
2011	33 756	4 243	224	949 979
2012	39 606	4 234	219	1 041 537
2013	41 412	4 216	221	1 062 464
2014	41 530	4 219	227	1 094 901
2015	42 096	4 222	220	1 111 467
2016	42 392	4 217	220	1 116 578
2017	40 652	4 202	227	1 117 537
2018	37 716	4 199	226	1 097 850
2019	35 595	4 192	227	1 056 977
2020	35 964	4 178	218	967 516
2021	37 379	4 187	220	1 016 213

Source: Professor Lawrence Edwards

5 All data for this section supplied by Prof. Lawrence Edwards. Data differs slightly from last year's report. Data were updated to include CPC codes H68 (Outright Export of goods manufactured in an Excise Warehouse) and others. The exclusion of these resulted in an underestimate of vehicle and food and beverage exports.

Table 5.6: Manufacturing exports characteristics

	Number of exporters	Number of products	Number of destinations	Number of transactions
2010	30 826	3 529	217	778 606
2011	31 677	3 527	221	862 942
2012	36 865	3 518	216	939 991
2013	38 605	3 502	215	959 266
2014	38 799	3 505	223	990 823
2015	39 354	3 506	215	1 006 994
2016	39 499	3 501	216	1 006 221
2017	37 849	3 488	224	1 011 669
2018	35 170	3 487	221	1 013 427
2019	33 266	3 484	224	997 123
2020	33 631	3 470	217	875 225
2021	35 071	3 478	220	922 487

Source: Professor Lawrence Edwards

Total exports and manufacturing exports have followed the same trajectory. Following the global financial crisis, the number of exporters expanded rapidly from 2010 to 2012. The rate of growth then tapered off. After 2016, the numbers of exporters declined. 2020 registered a small increase (4%), followed by a similar increase in 2021. The numbers of exporters in 2021 are 12% lower than the number of exporters in 2017.

The number of export transactions follow a similar trend: reaching a peak in 2016 and 2017 and declining thereafter. There was a significant decline in the number of export transactions in 2020. In 2021, the number of export transactions rose for both total and manufactures (5%) as compared to 2019. The number of transactions in 2021 was 9% lower than in 2017.

The number of products, both for total exports and for manufactures, has been slowly declining over the entire decade. The number of export products is 1,5 % lower in 2021 compared to 2010 for both total and manufactured exports.

From the perspective of innovation, the declines in the number of exporters and in the number of export products is of particular concern. Increasing levels of innovation would find expression in a rising number of exporters and in new export products.

Changes in exports can be decomposed into two categories. The first category, referred to as the intensive margin, represents changes in the value of exports by established exporters exporting existing products to established markets. The second category, referred to as the extensive margin, are changes in the value of exports arising from the entry/exit of new exporters or continuing exporters exporting new products, or exporting existing products to new destinations.

The intensive margin likely entails no additional innovation. By contrast, the extensive margin is the outcome of innovation. Indeed, this is the very definition of innovation.

Table 5.7 decomposes the contribution of the extensive and intensive margin to changes in export values.

The intensive margin makes a far larger contribution to changes in export values throughout the decade. Established exporters who export established products to established markets dominate South Africa's exports. The contribution of new exporters and of established exporters exporting new products and entering new markets is very limited.

Table 5.7: Decomposition of change in total exports: extensive and intensive margin

	Extensive margin % Contribution	Intensive margin % Contribution	Total % change
2011-12	1,6	-9,9	-8,3
2012-13	1,5	-3,0	-1,5
2013-14	2,8	-5,9	-3,1
2014-15	-0,7	-13,0	-13,7
2015-16	-0,2	-5,4	-5,6
2016-17	2,7	12,7	15,4
2017-18	0,1	6,6	6,7
2018-19	-1,5	-2,4	-3,9
2019-20	-0,6	-8,0	-8,6
2020-21	6,6	32,8	39,4

Source: Prof. Lawrence Edwards

Over the decade, price changes accounted for some three-quarters of the annual growth in the intensive margin across the period 2011 to 2019. The strong growth in exports in 2021 is dominated by the intensive margin. This is principally a result of higher prices for established mineral products, not increases in export volumes. Growth in export volumes on the part of the intensive margin have, over the decade, only made a minor contribution towards aggregate growth in export value.

Table 5.8: Decomposition of change in manufactured exports: extensive and intensive margin

	Extensive margin % contribution	Intensive margin % contribution	Total % change
2011	1,3	4,4	-5,7
2012	1,3	-3,6	-2,4
2013	0,3	-2,6	-2,4
2014	1,5	-0,0	1,5
2015	-0,5	-5,3	-5,8
2016	-1,2	-3,0	-4,2
2017	0,9	4,3	5,2
2018	1,7	2,4	4,2
2019	-0,7	-2,2	-3,0
2020	-0,8	-8,5	-9,4
2021	1,4	11,5	12,9

Source: Prof. Lawrence Edwards

The diversity of South African exports

South Africa's exports have become increasingly less diversified. The number of manufactured products and the number total products in which South Africa is competitive have declined consistently since 2012. Moreover, the rate of decline has accelerated since 2017, with a particularly significant decline in 2020. The number of manufactured products in which South Africa is competitive is 32% lower in 2020 as compared to a decade ago; for all products, the number is 28% lower.

Table 5.9: The diversity of South African exports, manufactured products and all products

	Manufactured products	All products
2010	197	312
2011	184	293
2012	201	317
2013	199	307
2014	194	303
2015	191	301
2016	175	281
2017	177	280
2018	169	275
2019	156	255
2020	134	225

Source: The Growth Lab, Harvard University

Note: The data is for Harmonised System products with a revealed comparative advantage (RCA) that is greater than 1; i.e., South Africa exports more than its "fair share" of the products' global share of exports.

5.2.4. Medium and high-technology manufacturing employment

Formal employment in manufacturing declined significantly in 2020 (-4,3%) and in 2021 (-1,0%). The numbers in formal employment in manufacturing in 2021 are the same as they were a decade ago. Employment in 2020 declined in both MHT (-2%) and in MHT excluding motor vehicles (-1,8%). Employment increased, albeit very marginally (less than 1%), in both MHT and in MHT excluding motor vehicles in 2021.

By contrast with overall manufacturing formal employment, over the decade, formal employment in MHT and in MHT excluding motor vehicles has tended to grow, albeit slowly. Employment in MHT in 2021 is 11% higher than a decade ago and employment in MHT excluding motor vehicles is 10% higher.

There has been an increase in the employment shares of both MHT and MHT excluding motor vehicles, particularly since 2017.

Table 5.10: Manufacturing, medium and high-technology manufacturing employment and % share

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Manufacturing employment ('000)	1 168	1 167	1 168	1 161	1 174	1 188	1 200	1 221	1 234	1 180	1 168
MHT employment ('000)	348	353	360	355	354	365	369	384	391	383	386
% Share of MHT employment	29,8	30,3	30,8	30,6	30,2	30,7	30,7	31,4	31,7	32,5	33,0
MHT employment, excl. motor vehicles ('000)	306	310	316	312	310	318	320	335	341	335	337
% share of MHT employment, excl. motor vehicles	26,2	26,6	27,0	26,9	26,4	26,8	26,7	27,4	27,6	28,4	28,9

Sources: Quantec & Stats SA

Note: The data are for formal employment

Regarding the different sectors within MHT manufacturing, percentage shares of employment have been largely stable over the last decade (**see Table 5.11**). The two sectors that have had some growth in their shares of manufacturing output, namely special-purpose machinery and motor vehicles, also exhibited a small increase in their share of employment over the decade.

Table 5.11: Medium and high-technology sectors employment % share

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Basic chemicals	6,81	7,38	7,45	6,94	6,35	5,90	6,05	6,06	5,85	5,76	5,57
Other chemical products	14,55	14,77	15,32	15,34	15,96	15,92	16,58	17,24	15,92	16,19	15,65
General purpose machinery	12,75	12,86	12,96	12,70	12,04	11,96	12,33	12,57	12,65	12,83	12,59
Special purpose machinery	15,31	14,83	14,83	15,27	15,28	14,97	15,75	16,12	16,56	16,86	16,59
Household appliances	1,84	1,85	1,84	2,01	1,93	1,96	1,93	1,68	1,61	1,83	1,84
Office, accounting, computing machinery	1,67	1,60	1,46	1,26	1,17	1,24	1,25	1,16	0,96	0,94	0,93
Electric motors, generators, transformers	3,70	3,57	3,94	4,45	4,46	4,35	3,92	3,96	3,94	4,62	5,20
Electricity distribution and control apparatus	1,78	1,81	1,57	1,64	1,91	1,89	1,93	1,87	1,84	1,75	1,77
Insulated wire and cables	1,43	1,48	1,44	1,40	1,38	1,36	1,29	1,17	1,19	1,16	1,15
Other electrical equipment	5,30	5,10	4,98	4,68	4,59	4,53	3,03	3,87	4,31	4,07	4,11
Radio, television and communication apparatus	1,81	1,73	1,82	1,95	1,92	1,94	1,92	1,79	1,71	1,73	1,79
Professional equipment	3,05	3,09	3,02	3,05	3,00	3,15	3,33	3,33	3,41	3,38	3,33
Motor vehicles	11,93	12,25	12,25	12,26	12,39	12,81	13,15	12,65	12,88	12,47	12,65
Parts and accessories	13,63	13,47	13,13	12,90	13,29	13,45	13,00	12,02	12,53	12,36	12,88
Other transport equipment	4,45	4,21	4,00	4,16	4,31	4,57	4,56	4,49	4,63	4,05	3,96

Sources: Quantec & Statistics South Africa

5.3. Innovation for social impact

South Africa is classified as a middle-income country, but still faces many socio-economic challenges, including poverty, high income and wealth inequalities and rising unemployment. For example, **Figure 5.2** shows that 20% of the population could be classified as "extremely poor". Other types of poverty remain high as well: lower-bound poverty was at 29% and upper-bound poverty at 42% in 2021.

For innovation systems to be embedded with the country's policy agenda, they have to devise solutions to the country's socio-economic and environmental problems.

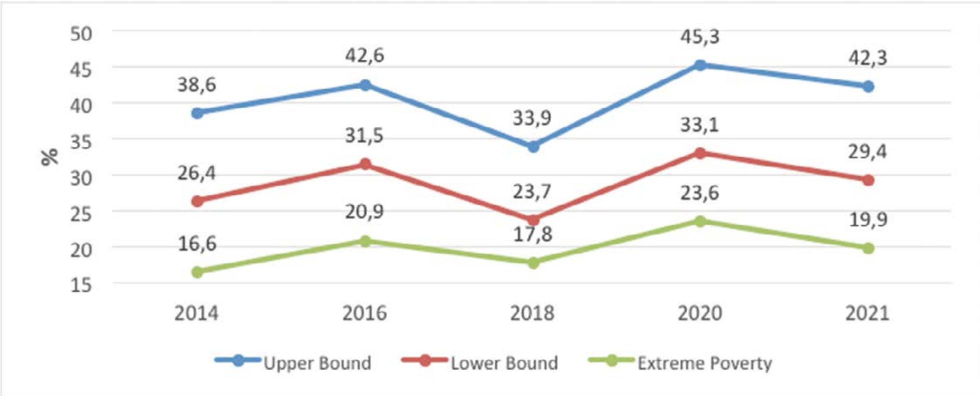


Figure 5.2: Poverty trends in South Africa
Source: Stats SA General Household Survey

Figure 5.3 shows the trends in the E-Government Development Index (EGDI). The EGDI is a global index used to measure how countries are using innovative technologies in ICT for inclusive development. It uses three indices to calculate the overall index: online services, telecommunication infrastructure and human capital. In 2022, the South African EGDI was 0,74, which is an improvement from 0,49 in 2012.

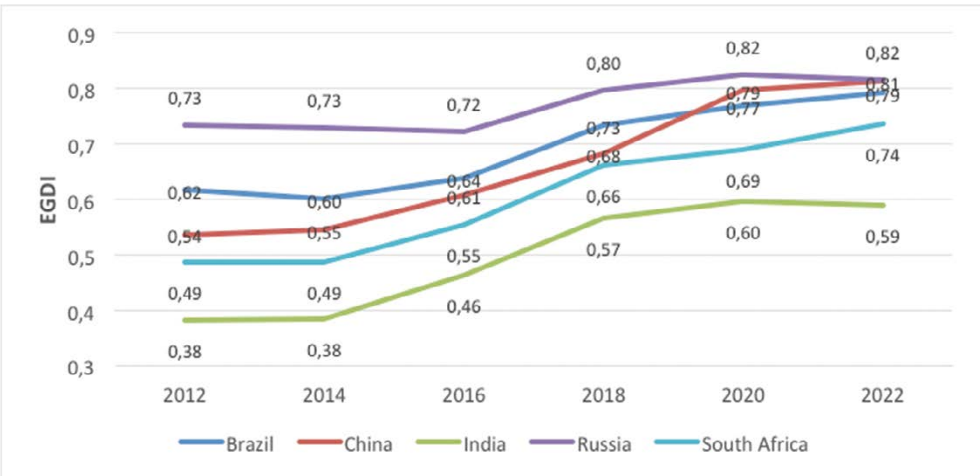


Figure 5.3: E-Government Development Index
Source: United Nations e-Government Knowledgebase

Table 5.12 shows other sub-indices of EGDI of South Africa in relation to other countries. South Africa improved its position globally, from being ranked 101st in 2012 to 65 out of 193 countries in 2022.

Table 5.12: E-Government Development Index

	Rank	Overall Index	e-Participation	Online services	Human capital		Tele infrastructure	
	2022	2012	2022	2012	2022	2022	2022	2022
Denmark	1	4	97	0,89	0,89	0,98	0,96	0,98
Finland	2	9	95	0,85	0,95	0,98	0,96	0,91
South Korea	3	1	95	0,93	0,94	0,98	0,91	0,97
USA	10	5	92	0,87	0,91	0,93	0,93	0,89
Russia	42	27	82	0,73	0,60	0,74	0,91	0,81
China	43	78	81	0,54	0,86	0,89	0,74	0,81
Brazil	49	59	79	0,62	0,90	0,90	0,80	0,68
South Africa	65	101	74	0,49	0,59	0,75	0,77	0,69
India	105	125	59	0,38	0,59	0,79	0,58	0,40

Source: United Nations e-Government Knowledgebase

Figure 5.4 shows results from the Inclusive Internet Index (III) of South Africa compared to other BRICS countries.

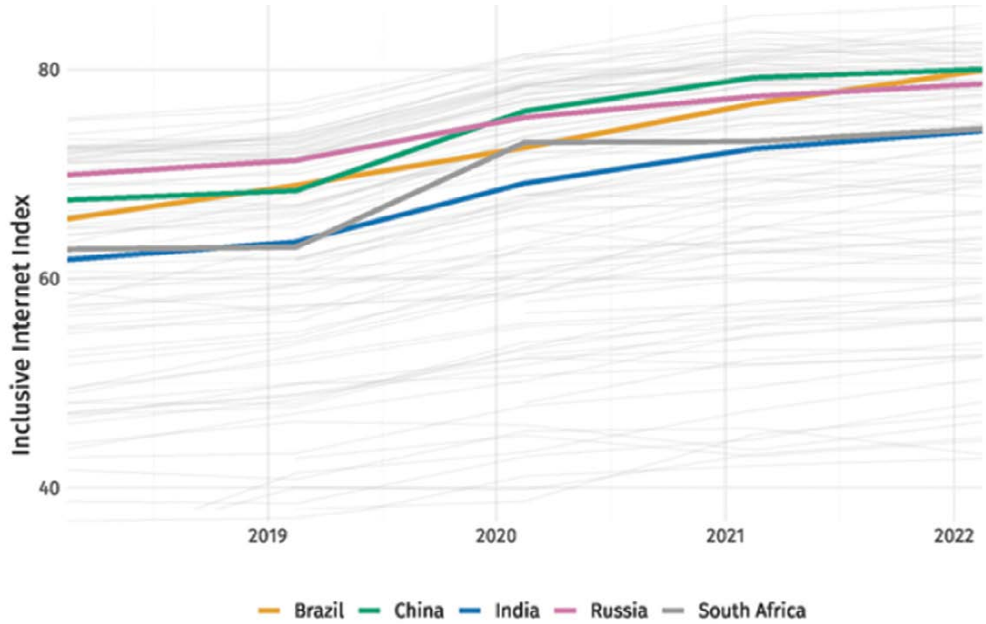


Figure 5.4: Inclusive Internet Index rankings for BRICS countries

Source: Economist Impact

The III aims to measure the level of internet accessibility and affordability, and its role in enabling social and economic goals. It focuses on four sub-categories to construct the overall index: availability, affordability, relevance and readiness.

As indicated in **Figure 5.4**, South Africa had an III score of 74 in 2022 and has been relatively improving from the score of 63rd in 2018.

Compared with other countries, South Africa is ranked 49th out of 100 countries and had a higher III score (74th) than the average of upper-middle income countries (**see Table 5.13**). Furthermore, South Africa scored higher in the four sub-categories.

Table 5.13: Benchmarking of Inclusive Internet Index

	Overall index		Availability	Affordability	Relevance	Readiness
	2022	2018	2022	2022	2022	2022
Singapore	86	75	90	89	81	72
USA	84	73	80	87	91	76
UK	83	72	79	90	82	77
China	80	68	78	83	87	68
Brazil	80	66	72	86	93	68
South Africa	74	63	70	80	75	74
India	74	62	62	86	82	71
High income	80	77	78	85	81	72
Upper-middle income	70	67	65	79	73	63
Lower-middle income	63	59	55	75	65	57
Low income	48	44	35	62	52	50

Source: Economist Impact

The Global Data Barometer (GDB) tracks the governments' use of data for public good, inclusive development and SDGs. It focuses on four themes to build the GDB score: capabilities, governance, availability, and use and impacts.

Figure 5.5 shows the 2021 GDB score for South Africa in relation to other countries. South Africa scores relatively lower (30) compared to other countries. It ranks lower than other BRICS countries: Brazil (40), India (47), and China (40).

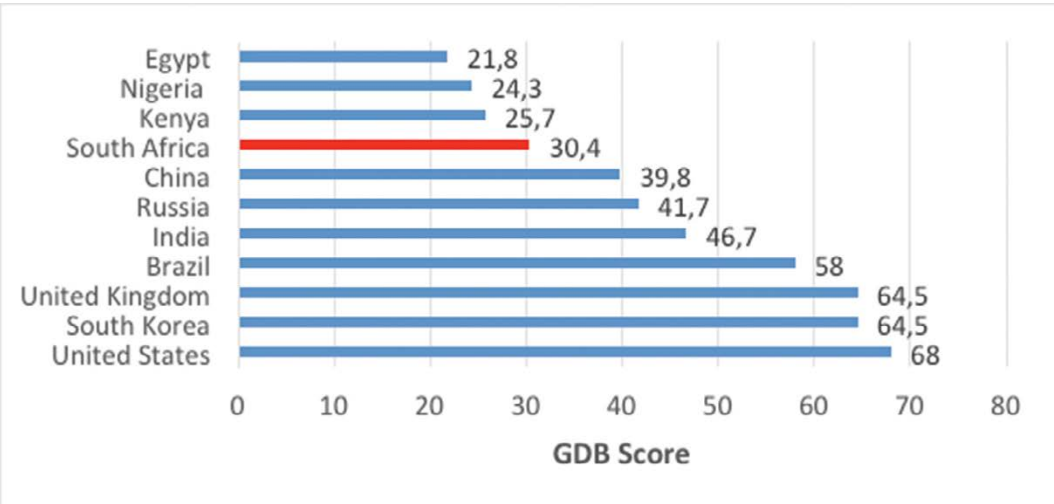


Figure 5.5: Benchmarking of Global Data Barometer Scores, 2022

Source: 2022 Global Data Barometer

Table 5.14 shows the individual scores of the GDB, showing that South Africa needs to improve in all categories, especially on climate action and land.

The Survey, Count, Optimize, Review, Enable (SCORE) global report was initiated by the WHO to classify how countries use health data to achieve health-related SDGs and improve their national health information systems. SCORE assesses countries' capacity to use data in the following areas:

- Survey population and health risks.
- Count births, deaths and causes of death.
- Optimise health service data.
- Review progress and performance.
- Enable data use for policy and action.

Table 5.14: The Global Data Barometer Score

	GDB Score	Capability	Governance	Public Finance	Public Procurement	Health & Covid-19	Company	Land	Climate Action	Political Integrity
USA	68	73	38	83	73	85	24	74	94	82
UK	65	78	63	57	61	60	83	33	73	60
S Korea	64	88	79	85	81	76	58	63	49	35
Brazil	58	59	68	71	78	73	53	55	75	45
India	47	57	50	47	42	55	65	36	29	38
India	47	57	50	47	42	55	65	36	29	38
Russia	42	61	35	79	82	22	33	60	24	32
China	40	63	35	36	60	28	45	61	30	26
South Africa	30	48	32	93	33	32	29	11	0	23
Ghana	28	49	32	70	1	17	45	5	32	6
Kenya	26	30	46	59	38	34	9	0	25	17

Source: 2022 Global Data Barometer

Table 5.15 shows that in the capacity to survey population and health risks, South Africa had a score of 4, which translates to a "well developed capacity". South Africa also scored higher than other upper-middle-income countries in the following categories:

- Count births, deaths, and causes of death (4: well-developed capacity)
- Optimise health service data (4: well-developed capacity)
- Review progress and performance (5: sustainable capacity)
- Enable data use for policy and action (5: sustainable capacity)

Table 5.15: Score for health data technical package

	Survey	Count	Optimise	Review	Enable
South Africa	4	4	4	5	5
India	4	3	4	5	4
China	5	4	5	5	4
South Korea	5	4	4	5	5
Malaysia	4	4	4	5	4
Cuba	4	5	5	5	5
Nigeria	3	1	3	4	3
United Kingdom	5	5	5	5	4
World average	3,2	3,1	3,1	3,7	3
Upper-middle income	3,1	3,6	3,1	3,4	2,9
Low income	2,9	1,3	3	3,5	2,7
Lower middle income	3,1	2,2	2,9	3,4	2,7
High income	3,6	4,6	3,5	4,1	3,6

Source: World Health Organization (2020)

Table **5.16** shows that more than 25 million South Africans use smartphones. Smartphones are enablers of accessing services such as effecting payments online for utilities, e-commerce, e-education, e-health, insurance and investments, media and entertainment, transport (e.g., Uber and Bolt) and food and beverages (e.g., Uber Eats).

Table 5.16: Smartphone users in South Africa

Year	Number (millions)
2014	9,70
2015	14,2
2016	16,4
2017	18,5
2018	20,4
2019	22,0
2020	23,3
2021	24,5
2022	25,5
2023	26,3 (projected)

Source: Taylor (2023)[6]

6 Taylor, P. (2023). Smartphone users in South Africa, 2014-2023.

6. SECTORAL AND PROVINCIAL SYSTEMS OF INNOVATION

This section analyses sectoral and regional systems of innovation to examine how NSI performance translates at the sectoral and regional levels.

6.1. Bioeconomy sector

The South African Bio-economy Strategy was approved in January 2014[7]. To avoid yearly fluctuations, the performance of the bioeconomy since the adoption of the strategy is assessed against a base: a three-year average of the period 2013 to 2015.

R&D expenditures in the field of biological sciences have been on a consistently downward trend since 2012/13. In 2020/21, there was a significant decline (13,8%) in real expenditure. In 2020/21, expenditures were 24% lower than in the base. Biological sciences' share of research expenditures in all fields has also tended to decline. It declined further in 2020/21 and was substantially lower than in the base.

Table 6.1: R&D expenditures in biological sciences and expenditures in biological sciences as a share of R&D expenditures

Year	R&D expenditure R'000s (constant 2015 Rands)	Share of R&D expenditures (%)
2011/12	1 664 407	6,1
2012/13	1 830 422	6,5
2013/14	1 755 467	6,2
2014/15	1 476 185	4,8
2015/16	1 452 763	4,5
2016/17	1 324 383	4,0
2017/18	1 384 769	4,0
2018/19	1 347 213	4,3
2019/20	1 375 769	4,9
2020/21	1 186 522	4,6
Base: 2013/14 -2015/16	1 561 471	5,2

Source: HSRC and DSI's National Survey of Research and Experimental Development. Statistical Report 2020/21.

In contrast to the decline in resources committed to R&D in the biological sciences, there has been a significant increase in the number of biotechnology publications since the adoption of the bioeconomy strategy. There was a significant increase in publications in 2019 as compared to 2018 (23%). Moreover, South Africa's global share of biotechnology publications also increased significantly. There were declines in publication outputs and the world share of South African publications in 2020 and 2021. Nevertheless, both the number and the world share of South Africa's publications in biotechnology have increased significantly since the adoption of the bioeconomy strategy.

7 https://www.gov.za/sites/default/files/gcis_document/201409/bioeconomy-strategya.pdf

Table 6.2 South Africa number and world share of biotechnology and applied microbiology publications (articles and reviews only)

Year	Number of publications	World share (%)
2011	252	0,892
2012	150	0,579
2013	187	0,645
2014	241	0,786
2015	183	0,589
2016	221	0,741
2017	235	0,734
2018	238	0,775
2019	282	0,881
2020	277	0,797
2021	265	0,753
Base: 2013 – 15	204	0,673

Source: CREST, Stellenbosch University version of the Clarivate Analytics Web of Science

The bioeconomy strategy has three key economic objectives: increase the contribution of the bioeconomy to GDP through high growth, create more employment and make the country more competitive. The data presented here are for what has been identified as the "core" of the bioeconomy. This consists of the following: SIC1, SIC30, SIC321 – SIC326, SIC391, SIC392 – SIC395. [8]

Output declined in 2019 and 2020. In 2021, there was a significant increase in output over the previous year (7%). There has been no consistent tendency for the bioeconomy to grow its share of total South African output since the adoption of the bioeconomy strategy. However, 2020 and 2021 have seen some increase in the share of the bioeconomy.

Table 6.3: Bioeconomy GDP output and share of total South African GDP

	Bioeconomy GDP output (R' million at constant 2015 prices)	Bioeconomy's share of total GDP (%)
2011	300 007	8,08
2012	305 325	8,07
2013	308 490	7,96
2014	319 083	8,11
2015	316 434	7,95
2016	311 091	7,75
2017	331 680	8,17
2018	336 146	8,16
2019	328 263	7,98
2020	322 180	8,29
2021	345 531	8,48
Base: 2013-15	314 669	8,00

Source: Quantec & Stats SA

8 The data presented here differ from the data presented in the STI Indicator Report last year. Wood and paper, and furniture and other manufacturing products are now included in the bioeconomy "core".

The numbers of employment in the bioeconomy have been declining consistently since 2015. In 2021, there was a further marginal decline in employment (-0,3%). This decline in employment is in sharp contrast to the increase in output. The share of the bioeconomy in total South African employment in 2020 and 2021 (10,7%) was marginally lower than the yearly average for the period 2013 to 2015 (10,9%).

Table 6.4: Bioeconomy sector employment +

	Bioeconomy employment	% Total SA employment
2011	1 473 867	10,3
2012	1 523 185	10,4
2013	1 605 942	10,7
2014	1 572 579	10,3
2015	1 821 920	11,6
2016	1 781 840	11,3
2017	1 750 643	10,9
2018	1 728 390	10,6
2019	1 718 500	10,6
2020	1 612 365	10,7
2021	1 608 516	10,7
Base: 2013 -15	1 666 814	10,9

Source: Quantec & Stats SA

Note: Total employment = formal + informal employment

A key objective of the bioeconomy strategy is to increase exports and South Africa's competitiveness in global markets. In addition to increasing total bioeconomy exports, the strategy aims to increase the value of South Africa's bioeconomy exports. As a result of enhanced technological change and innovation, exports should be more sophisticated and hence of higher value.

Bioeconomy exports have shown no tendency to increase. In 2020, bioeconomy exports were below the average for 2015. However, in 2021, bioeconomy exports increased significantly (27,8%).

Over the decade, there has been no tendency for the bioeconomy share of total South African exports to increase. The bioeconomy share of total South African exports in 2021 (15,7%) was below its base share of total South African exports (17,5%).

The USD unit value of bioeconomy exports has tended to decline since 2017. However, the USD unit value of bioeconomy exports rose significantly in 2021. In 2021 the unit value (USD0,89) was above the average for 2013 to 2015 (USD0,84).

Table 6.5: Bioeconomy sector's exports

	Bioeconomy exports (current US$ millions)	% of total South African exports	Unit value US$
2011	16 799	15,6	-
2012	15 873	16,0	-
2013	16 362	17,2	0,78
2014	15 945	17,2	0,89
2015	14 526	18,0	0,85
2016	14 162	18,6	0,87
2017	15 971	18,0	0,88
2018	16 839	17,9	0,86
2019	15 048	16,8	0,75
2020	15 102	17,6	0,77
2021	19 304	15,7	0,89
Base: 2013-15	15 611	17,5	0,84

Source: Quantec & Stats SA

The strong performance in terms of science (publications) contrasts with the weak performance in the economic magnitudes (output, employment and exports) in the bioeconomy.

6.2. Emerging technologies and the South African high-technology sector

This section analyses the state of the 4th Industrial Revolution (4IR) in South Africa through the high-technology sector and the emerging technologies lens. The semiconductor industry is used as a unit of analysis for the high-technology sector as semiconductors are used in products for various STI Decadal Plan priority sectors, such as energy, agriculture, water, manufacturing, circular economy, etc. Furthermore, the state of competitiveness of the country's high-technology industry is demonstrated through defence-sector manufactured products. Lastly, the state of advancements in semiconductor technology is determined through patents analysis and there is an analysis of the state of science and technology for 4IR-related technologies.

6.2.1. Competitiveness of the semiconductor industry in South Africa

During the period 2005 to 2012, the country's exports and imports of semiconductor devices showed a good balance of trade (**see Figure 6.1**). However, in 2013 the ratio of imports to exports of semiconductor devices was 35:1. In 2020, this ratio decreased to 20:1, with both imports and exports being low. This shows that the struggling semiconductor industry in South Africa is more dependent on imports.

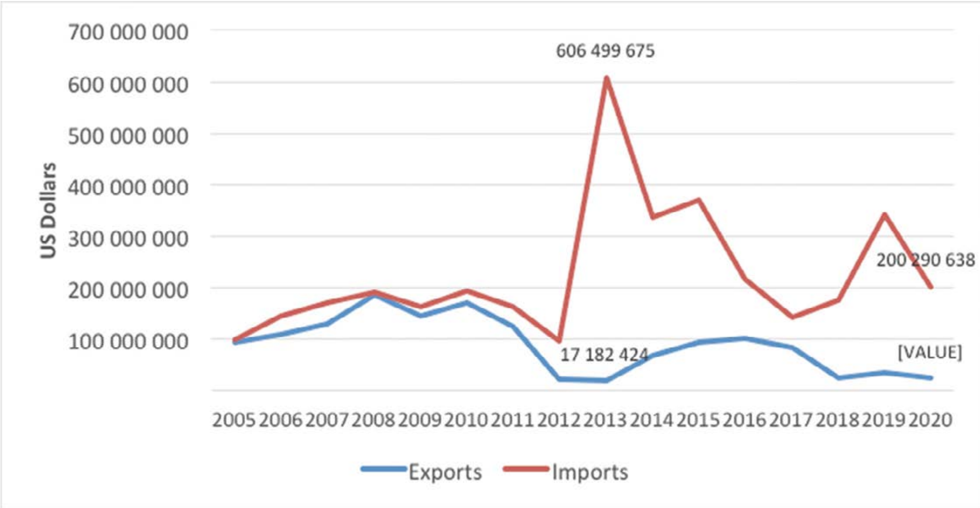


Figure 6.1: Exports and imports of semiconductor devices
Source: The Observatory of Economic Complexity

A decline in competitiveness of the South African semiconductor industry is made clear in **Figure 6.2** when comparing its exports against those of world total, Africa and the BRICS group of countries. For an analysis period of 2005 to 2020, there is a notable decline in exports of semiconductor devices as a share of the world's total exports, from 1,67% in 2005 to 0,02% in 2020. In comparison to Africa and BRICS, a share of South Africa semiconductor device exports shows two periods of increase and eventual decline in competitiveness (2006 – 2012 and 2013 – 2018). The best level reached in comparison with Africa was in 2009 with a share of 21,83%. During a renewed wave of competitiveness for this industry, South Africa's share of Africa's semiconductor devices exports reached 20,96% in 2016.

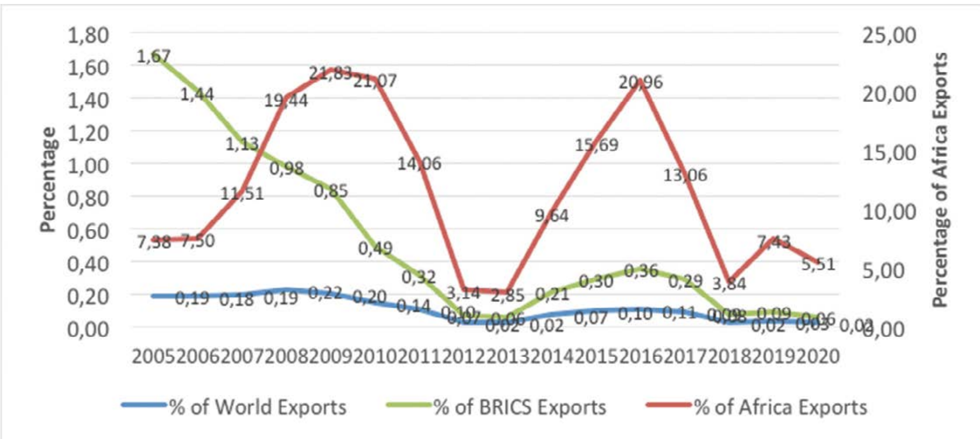


Figure 6.2: Share of South African exports of semiconductor devices
Source: OCE Data

Figure 6.3 shows that the annual number of South African semiconductor patents remains low, with only eight patent publications both in 2020 and 2021. South Africa's world share of semiconductor patents decreased from a high point of 0,015% in 2012 to only 0,006% in 2021. Therefore, the competitiveness of the South African semiconductor industry is also low in terms of technological capability.

Figure 6.3: Semiconductor patents from South Africa
Source: WIPO Patentscope

6.2.2. Defence sector

Since the defence sector relies heavily on semiconductor technology, it is ideal for assessing performance of downstream industries. Authorised defence product exports from 2005 to 2021 show a trend similar to that of semiconductor device exports (**see Figure 6.4**). During 2015 to 2012, this sector experienced good growth in exports, coupled with a relative reduction in imports authorisations. This was followed by a dip similar to that of semiconductor device exports. The trade balance for this sector has always been positive. In 2021, defence products export authorisations amounted to R3 353 million compared to R121 million in imports. This translates to an exports-to-imports ratio of 27:1.

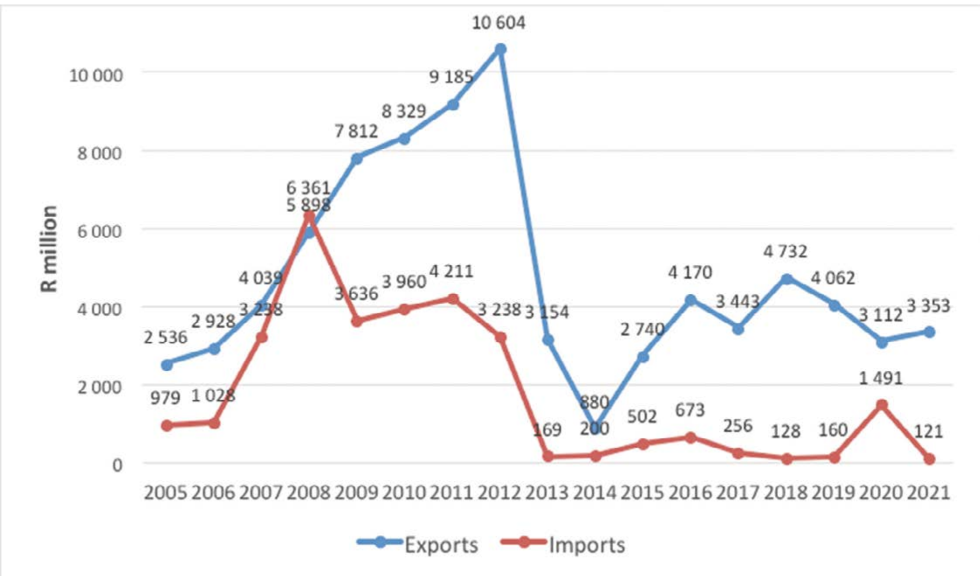


Figure 6.4: Exports and imports of defence products
Source: National Conventional Arms Control Committee Annual Reports

Table 6.6 shows the distribution of defence products export authorisations. Although armoured combat vehicles had a large export authorisation share in 2013 (76,81%), imaging and countermeasure equipment as well as ammunitions have recently increased their share of defence products export (22,71% and 22,19% respectively in 2021). Other defence products that have experienced a decline in their share of export authorisations are missiles and missile launchers as well as bombs and rockets.

There has been a recent emergence of exports of some defence products that rely heavily on semiconductors. These are combat aircraft, attack helicopters and warships. A closer inspection of the products category of "technology" shows that it includes products such as armoured combat vehicles, measuring equipment, countermeasures, rockets, unmanned aerial vehicles, etc. Therefore, this category can simply be classified as miscellaneous products as it combines different existing categories.

What is missing from this list are defence products such battle tanks, where the only case of authorised export for the assessment period was a donation that had no monetary value attached to it.

Table 6.6: Percentage distribution of defence product exports

	2013	2014	2016	2017	2018	2019	2020	2021
Armoured combat vehicles	76,81	32,91	42,74	52,93	18,63	29,67	23,75	15,39
Large calibre artillery	0,00	11,85	0,00	0,00	2,70	5,23	1,00	0,63
Combat aircraft	0,00	0,00	0,00	0,00	0,04	4,58	4,08	2,38
Attack helicopters	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,18
Warships	0,00	0,00	0,00	0,00	0,00	0,08	0,33	6,24
Small weapons	0,00	0,00	0,00	0,00	0,80	0,00	0,00	0,00
Missiles and missile launchers	0,27	0,40	14,23	1,12	3,71	0,17	0,00	0,00
Light weapons	0,03	2,86	1,48	2,55	2,18	0,36	0,10	7,42
Heavy weapons	0,56	7,72	2,02	5,07	0,00	0,00	0,00	0,00
Bombs and rockets	1,82	15,32	15,42	16,73	14,52	7,13	10,36	5,51
Ammunition	4,31	2,73	5,36	15,71	24,58	20,72	31,40	22,19
Fire control and related alerting and warning equipment	0,14	2,93	6,40	1,33	20,55	3,74	10,52	6,53
Electronic equipment	7,01	12,39	7,43	0,27	7,38	9,71	6,21	9,08
Imaging or countermeasure equipment	9,06	10,72	4,80	3,87	3,81	18,36	9,79	22,71
Software	0,00	0,16	0,11	0,41	0,21	0,23	2,46	0,34
Technology	0,00	0,00	0,00	0,00	0,89	0,00	0,00	1,39

Source: National Conventional Arms Control Committee Annual Reports

Some of the defence technologies can also be used for civilian applications in other sectors, hence the term "dual use". As a signatory to the 1996 Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, South Africa started to report on exports of dual-use technologies. In terms of the authorised exports amount, dual-use technologies and goods exports are still relatively small. In 2020 and 2021 their exports as percentage of defence product exports were 6,65% and 6,40% respectively.

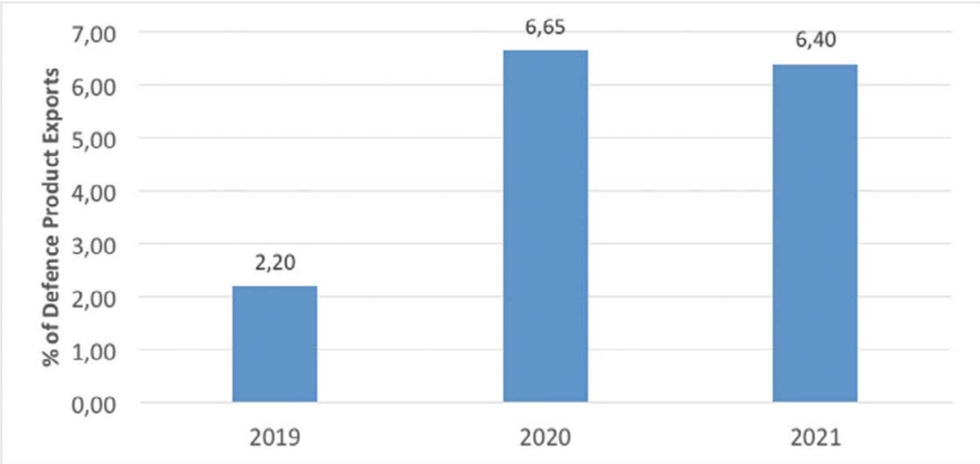


Figure 6.5: Dual-use technologies exports as percentage of defence product exports
Source: National Conventional Arms Control Committee Annual Reports

6.2.3. The future of the high-technology sector through emerging technologies

Most high-technology stakeholders have concluded that 4IR technologies should not necessarily be built from scratch but can leverage on existing products' technology platforms. As semiconductors were the building block of the third industrial revolution, their incorporation into emerging technologies such as nanotechnology, biotechnology and Internet of Things (IoT) will likely drive the implementation of 4IR technologies.

Figure 6.6 shows the world's proportion of semiconductor patents that incorporated nanotechnologies, biotechnologies and IoT. Although biological semiconductor patents are leading (10,64% in 2021), their growth during 2011 to 2021 is very low compared to the IoT-based semiconductor patents that increased from a proportion of 0,03% in 2011 to 8,02% in 2021. The nanosemiconductor patents' proportion remained low at 0,76% in 2021.

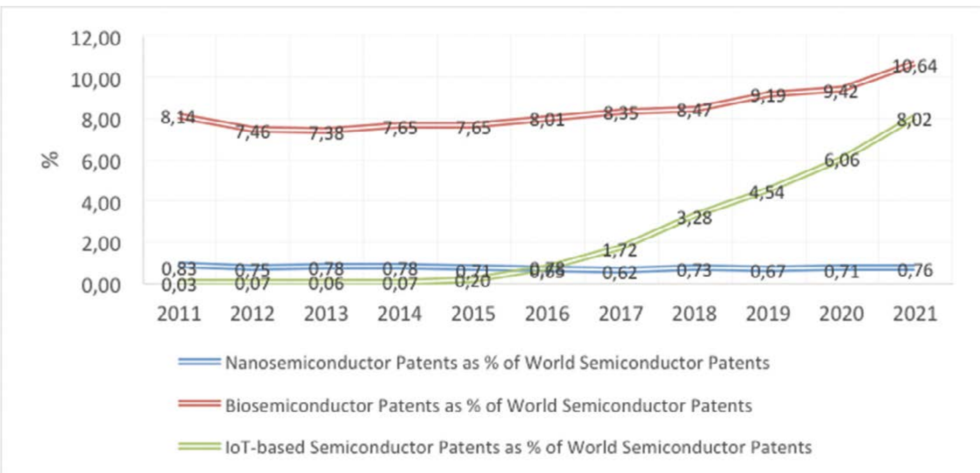


Figure 6.6: Trends in proportion of world emerging technologies-based semiconductors patents
Source: WIPO Patentscope

During the period 2011 to 2021, 10 nanosemiconductor patents originated from South Africa (**see Table 6.7**) as deduced from the World Intellectual Property Organization (WIPO) database. The applicants show a good balance between various actors within the NSI (universities, Small, Medium and Micro Enterprise's (SMME), a large company and a science council). All three patents from universities are relatively recent (2018, 2016 and 2015).

The patents from the University of Zululand and the University of KwaZulu-Natal are both for the manufacturing of nanomaterials that can be used in building advanced semiconductors.

Stellenbosch University's patent is an example of technology convergence as it is a biosemiconductor for detection of biomolecules that also makes use of nanotechnology. CSIR's patent is for a nanoscale transistor and gas detector.

Table 6.7: Nanotechnology-based semiconductor patents from South Africa

Patent title	Applicant	Publication year
Assembling and packaging discrete electronic component	PST Sensors (Pty) Ltd	2012
Cooling of semiconductor devices	Individual	2012
Detonation of explosives	AEL Mining Services Ltd	2012
Method of producing nanoparticles by generating an electrical spark	PST Sensors (Pty) Ltd	2013
Nylon compositions for forming cast nylon and cast nylon parts	Advanced Nylons (Pty) Ltd	2013
A field effect transistor and a gas detector including a plurality of field effect transistors	CSIR	2014
Current switching transistor	PST Sensors (Pty) Ltd	2014
The synthesis of core-shell metal-semiconductor nanomaterials	University of Zululand	2015
Systems and methods for detection of biomolecules	Stellenbosch University	2016
Electroconductive composite	University of KwaZulu-Natal	2018

Source: WIPO Patentscope

About 10 patents were also published for biosemiconductors. Similar to the nanosemiconductor patents, they originate from the different role players within the NSI (**see Table 6.8**). These types of specialised semiconductors are used in medical and biological applications such as drug discovery and delivery, in-vivo tissue engineering, and detection and analysis of biological materials, etc.

For an analysis period 2011 to 2021, there was no semiconductor patent from South Africa that incorporates IoT technology. This is an important area of focus if South Africa is to fully participate in the 4IR.

Table 6.8: Biotechnology-based semiconductor patents from South Africa

Patent title	Applicant	Publication year
On-chip 4D lightfield microscope	CSIR	2012
Micro optical device	INSiAVA (Pty) Ltd	2012
Material analysis system, method and device	CSIR	2013
Superhydrophobic coatings and methods of preparation	Individual	2013
Systems and methods for detection of biomolecules	Stellenbosch University	2016
Therapy system for transcutaneous in-vivo tissue engineering	Euvaira Biotechs (Pty) Ltd	2016
System and method for marking and identifying an object	Royal Square Investments CC	2018
Non-volatile resistive random access memory and a manufacturing method thereof	University of South Africa	2020
An electronic circuit that generates a high-impedance load and associated method	INSiAVA (Pty) Ltd	2021
System and method for infusion of drugs	University of Cape Town	2021

Source: WIPO Patentscope

6.2.4. Capabilities in emerging technologies

This sub-section analyses three high-growth technologies internationally to understand the performance of the South African innovation system based on publication and patent outputs. The areas considered are nanotechnology, biotechnology and digitalisation. These have already been captured as important areas of growth in government strategy documents. Additionally, these are some of the key building blocks to the government's push towards 4IR. The areas of nanotechnology and biotechnology are well established and have been reported on in the past, but digitalisation has not. Digitalisation is the use of digital technologies to change a business model and the process of moving to a digital business. Artificial Intelligence (AI) is a driving force behind digital transformation, encompassing innovations such as machine learning, 3D printing, IoT, data labelling platforms and predictive analytics. Companies pursue digital transformation in response to consumers' growing demands and to increase efficiencies and lower costs.

Table 6.9 shows patenting trends in the three high-tech sectors, with biotechnology showing a higher level of inventiveness than the other two emerging technology fields. Digitalisation is still at its earliest stage of development, as seen from the lower level of patenting in this field on a yearly basis.

Table 6.9 patenting trends in select emerging technologies

	Digitalisation	Nanotechnology	Biotechnology
2010	1	3	10
2011	0	8	14
2012	1	7	8
2013	1	4	15
2014	1	5	20
2015	2	4	13
2016	3	6	14
2017	4	3	11
2018	5	2	12
2019	3	3	4
2020	5	6	13
2021	2	5	8

Source: WIPO Patentscope

Figure 6.7 shows an illustration of the patenting trends in the three fields. The organisations responsible for most of the patenting in the digitalisation area are the UCT, with three patents, and Stellenbosch University, with two patents. The companies that are active in this area include the security firm Fidelity ADT.

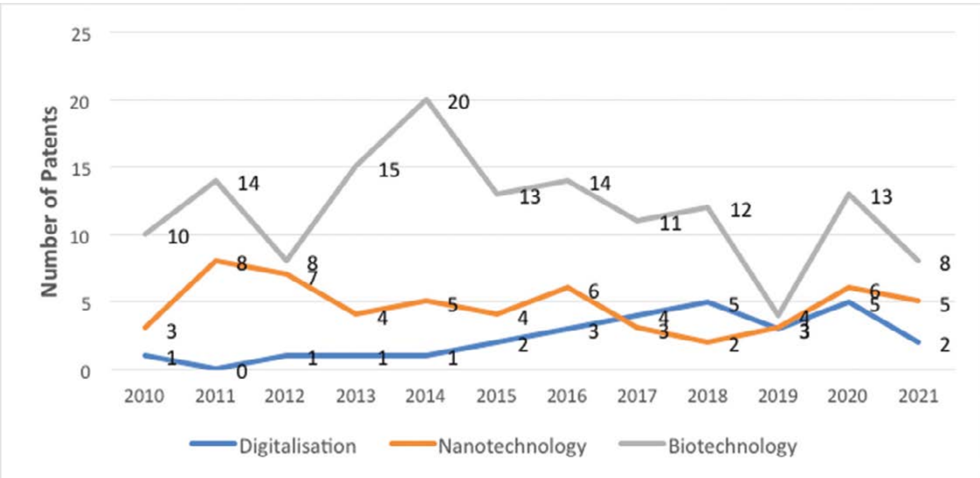


Figure 6.7 Trends in patenting for the three emerging areas

Source: WIPO Patentscope

In the biotechnology sector, a lot of activity occurs in the Western Cape province, with UCT (36) having the most patents in this area followed by Stellenbosch University (29). Stellenbosch University also has the highest number of nanotechnology patents at 11 followed by the University of the Witwatersrand with 10. There are some start-up companies such as PST Sensors and Rubber Nano Products that are also patenting in this sector.

Table 6.10 shows the percentage share of patents by South African-based innovators as a proportion of overall patents granted annually worldwide. Looking at all sectors, South Africa tends be at around 0,03% in the 10 years under review. The three sectors are in line with this trend, with biotechnology underperforming slightly in most of these years.

Table 6.10: South Africa's world share of patents

	Digitalisation	Nanotechnology	Biotechnology	All sectors
2010	0,03	0,03	0,02	0,03
2011	0,00	0,06	0,02	0,03
2012	0,03	0,06	0,01	0,03
2013	0,02	0,03	0,02	0,03
2014	0,02	0,04	0,03	0,03
2015	0,03	0,03	0,02	0,03
2016	0,03	0,04	0,02	0,03
2017	0,03	0,02	0,02	0,02
2018	0,03	0,01	0,02	0,02
2019	0,02	0,02	0,01	0,02
2020	0,03	0,06	0,03	0,03
2021	0,03	0,11	0,06	0,04

Source: WIPO Patentscope

Table 6.11 shows the growth that has taken place in South Africa in the areas of nanotechnology and digitalisation. For digitalisation, the country's institutions produced a total of 171 publications in 2011, which grew to 1 239 in 2021, representing a compound annual growth rate of 21%. For nanotechnology, they grew from a low of 279 in 2011 to 2 174 in 2021, a growth rate of 22%. Biotechnology did not show any significant growth during this period.

Table 6.11: Publications in emerging focus areas

	Digitalisation	Nanotechnology	Biotechnology
2010	150	238	210
2011	171	279	236
2012	192	343	144
2013	253	687	187
2014	247	778	234
2015	428	857	191
2016	470	1 101	219
2017	572	1 190	208
2018	809	1 391	225
2019	921	1 759	300
2020	981	2 091	264
2021	1239	2 174	251

Source: Web of Science Core Collection

Looking at all fields, the country's publication share has risen from around 0,5% in 2011 to almost 1% in 2021. Once again, the two fields, nanotechnology and digitalisation, have been growing their share while biotechnology has shown no growth over the period.

Table 6.12: Percentage share of publications for South Africa in emerging technologies

	Digitalisation	Nanotechnology	Biotechnology	All Fields
2011	0,34	0,20	0,85	0,56
2012	0,44	0,23	0,54	0,62
2013	0,52	0,42	0,65	0,62
2014	0,38	0,44	0,76	0,65
2015	0,52	0,45	0,63	0,68
2016	0,51	0,54	0,78	0,73
2017	0,56	0,54	0,68	0,74
2018	0,62	0,56	0,74	0,82
2019	0,60	0,67	0,91	0,84
2020	0,63	0,78	0,76	0,91
2021	0,66	0,77	0,72	0,94

Source: Web of Science Core Collection

Figure 6.8 shows that, of the three technologies, nanotechnology and digitalisation seem to be showing the highest growth based on academic publications, with biotechnology essentially stagnant.

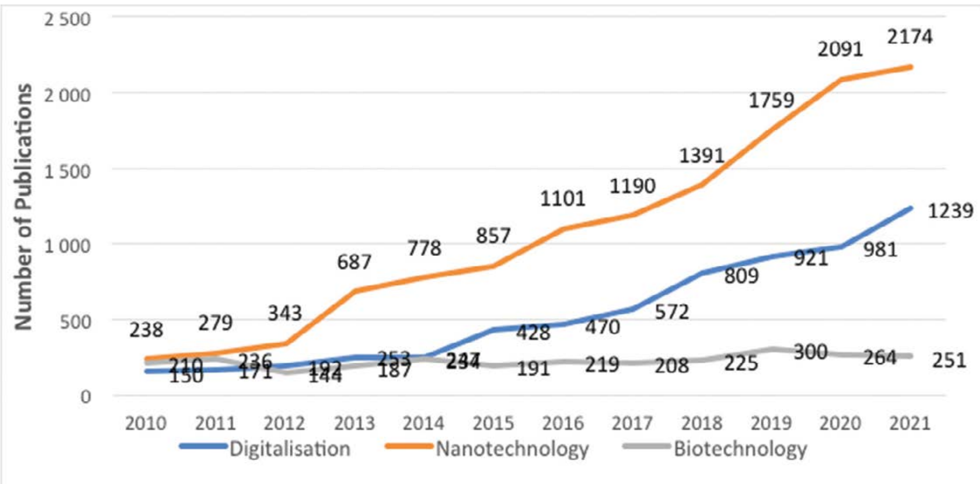


Figure 6.8: Trends in publications for the three emerging technologies

Source: Web of Science Core Collection

6.3. Regional systems of innovation

The provincial STI report is the provincial extension of the NSI performance assessment. It is intended to provide information on RDI at the provincial level. The provincial dimension is important since the NSI is made up of regional and local innovation systems. Moreover, there is a growing recognition of the regional dimension in national innovation strategies in harnessing localised assets and improving policy impacts.

This section conducts a comparative assessment of research and innovation of the nine provinces in South Africa with a limited set of indicators. The provincial report uses some of the indicators in the conceptual framework for this report. Ideally, it should present the same indicators, however, most of the data is not available at the provincial level.

6.3.1. Provincial economic performance and industrial structure

This section presents regional economic indicators to illustrate the impact of structural differences on the innovation indicators. What follows is a brief analysis of the provincial economic and industrial structures.

The sizes of the nine provincial economies in South Africa and their contribution to GDP differ considerably. As shown in **Table 6.13,** Gauteng dominates, with an economy of R1,58 trillion in 2021. KwaZulu-Natal has the second-highest GDP (R728 billion) followed the by Western Cape (R636 billion). Gauteng, KwaZulu-Natal and Western Cape collectively contribute more than half of the country's value added, reported to be about 64%.

Table 6.13: Sizes of provincial economies in South Africa

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	R billion (constant 2015 prices, seasonally adjusted and annualised)									
Eastern Cape	331	336	338	341	344	346	350	349	330	353
Free State	220	225	228,5	228,7	228,9	231	233	232	217	227
Gauteng	1 470	1 511	1 538	1 557	1 576	1 591	1 620	1 628	1 514	1 584
Limpopo	281	287	290	296,1	296	299	303,5	303,3	287	298
Mpumalanga	289	294	301	302	303	306	310	309	290	316
Northern Cape	85	87	89	90,7	90,3	92	93	92,8	89	93
North West	245	252	245	254	248	252	255	254	236	264
KwaZulu-Natal	678	696	709	717	723	734	745,8	745,5	696	728
Western Cape	595	610	621	631	638	646	656	657	618	636

Source: Quantec

This disparity in economic size and economic structures has a bearing on provincial innovation systems.

6.3.2. Revealed comparative advantage.

The Revealed Comparative Advantage (RCA) shows another perspective of provincial economic performance. The provincial GVA data for a period 2011 to 2021 has been used to compute RCA values. An RCA value of 1 indicates a normal expected economic activity for a specific industry and province; RCA of greater than 1 shows the economic activity that is above the expected level; and RCA of less than 1 shows lower than normal economic activity.

As shown in **Table 6.14,** different provinces specialise in different industries and may show less strength in other industries. For example, Gauteng specialises mainly in finance, real estate and business services (RCA = 1,22), followed by community, social and other services (1,16), manufacturing (1,13) and transport and communication (1.02). These values show that there is some balance in the level of dominant economic activities as there is no industry that has RCA of significantly above 1. Due to urbanisation, the only industry that is performing far below the normal expected economic activity level at Gauteng (RCA = 0,18) is agriculture, forestry and fishing. The Western Cape province specialises in agriculture, forestry and fishing (RCA = 1,45), followed by construction (1,37), finance, real estate and other personal services (1,23).

Table 6.14: Revealed comparative advantage of provinces based on gross value added, 2011-2021

	Eastern Cape	Free State	Gauteng	KwaZulu-Natal	Limpopo	Mpumalanga	North West	Northern Cape	Western Cape
Construction	1,02	0,66	0,95	1,13	0,9	0,86	0,71	0,73	1,37
Electricity & water	0,59	1,18	0,86	1,03	1,27	2,21	0,94	1,17	0,73
Manufacturing	0,89	0,83	1,13	1,32	0,26	1,08	0,44	0,26	1,1
General government services	1,2	1,38	0,85	1,03	0,82	0,73	1,41	0,96	1,13
Finance, real estate & business services	0,95	0,81	1,22	0,84	0,75	0,62	0,69	0,72	1,23
Community, social & other personal services	1,3	0,99	1,16	0,93	1,22	0,74	0,81	1,02	0,63
Wholesale & retail trade; hotels & restaurants	1,33	0,97	0,89	1,00	1,11	1,04	0,86	0,87	1,11
Transport & communication	0,89	1,05	1,02	1,34	0,55	0,7	0,67	1,32	1,07
Mining & quarrying	0,03	1,26	0,29	0,19	3,7	3,23	4,37	2,83	0,03
Agriculture, forestry & fishing	0,7	2,13	0,18	1,65	1,14	1,26	1,13	3,29	1,45

Source: computed from Quantec

The Eastern Cape specialises mainly in wholesale and retail as well as hotels and restaurants (RCA = 1,33), community, social and other personal services (1,30) and general government services (1,20). The North West is the mainly a mining province (RCA = 4,37), followed by Limpopo (3,7), Mpumalanga (3,23) and the Northern Cape (2.83). A decrease in gold mining activities in the Free State is shown by an RCA of 1,26, which is too low compared to the three mining provinces. Instead, Free State specialises in agriculture, forestry and fishing (RCA = 2,13) followed by general government services (1,38). The Northern Cape shows the highest specialisation in agriculture, forestry and fishing (RCA = 3,29).

An activity level of other industries such as transport and communication can be interpreted in the context of other industries. For example, KwaZulu-Natal has the highest specialisation in transport and communication (RCA = 1,34). The related industries that are likely to be driving this industry are agriculture, forestry and fishing (1,65) and manufacturing (1,32).

Provincial RCA values can be used in the context of the STI Decadal Plan priorities. For the revitalisation of established sectors of agriculture, manufacturing and mining, the provinces that are positioned to pilot and upscale the related niche innovations are as follows: agriculture (Northern Cape, Free State, KwaZulu-Natal, Western Cape and Mpumalanga), manufacturing (KwaZulu-Natal, Gauteng, Western Cape and Mpumalanga) and the identified mining provinces. The Western Cape and Gauteng are ideal to lead the digitisation priority due to high RCA on finance, real estate and business services. Digitisation through government services can be piloted in provinces such as the North West, Free State and Eastern Cape, where the RCA is high for general government services.

6.3.3. Indicators for provincial innovation systems

In this section, selected input indicators for the provincial innovation systems are presented. These include R&D expenditure, NSC performance in Maths and Science and access to the internet.

Provincial R&D expenditure

R&D is of fundamental importance in the creation of knowledge, products and technologies. Investment in research and development is an important input and contributes to provincial economic development. Table 7.15 shows provincial R&D expenditure for the nine provinces between 2016/17 and 2020/21. The data shows that between these financial years, Gauteng continued to perform most of the R&D in the country, with its share increasing by R332 million to R14,717 billion in 2020/21. It is followed by the Western Cape (R8,3 billion) and KwaZulu-Natal (R3,2 billion). This is expected, because these provinces have high numbers of leading public research institutions and universities, high-technology industrial activities and/or knowledge-based services, which attract new start-ups and highly qualified personnel.

Table 6.15: Provincial R&D expenditure trends

	GERD	Eastern Cape	Free State	Gauteng	KwaZulu-Natal	Limpopo	Mpumalanga	Northern Cape	North-West	Western Cape
	R'000									
2016/17	35 692 973	2 206 473	1 834 572	16 421 582	3 639 100	728 874	699 720	532 530	1 298 778	8 331 345
2017/18	38 724 590	2 300 631	2 149 267	17 319 635	4 172 713	854 885	715 616	576 963	1 306 478	9 328 402
2018/19	36 783 968	2 211 524	1 976 953	15 767 101	4 074 154	806 624	853 859	905 844	1 682 406	8 505 504
2019/20	34 484 862	2 091071	1 711 039	14 385849	3 629 403	772 074	841 877	900 545	1 700 184	8 542 820
2020/21	33 541 332	1 998 900	1 241 827	14 717 743	3 278 682	983 369	706 459	867 333	1 364 854	8 382 165

Source: HSRC and DSI National Survey of Research and Experimental Development

As **Figure 6.9** shows, although Gauteng has the highest proportional R&D expenditure, there has been a decline from 46% in 2016/16 to 44% in 2020/21. On the other hand, the Western Cape has increased its proportional R&D expenditure from 23% to 25% in the same period.

The data illustrates the significant disparities in R&D expenditure among the provinces. R&D expenditure is concentrated in Gauteng, the Western Cape and KwaZulu-Natal and, in 2020/21, these provinces contributed almost 80% to national R&D expenditure.

This unbalanced R&D landscape has implications on innovation performance as R&D intensity is frequently used as a measure to determine an economy's creative/innovative capacity.

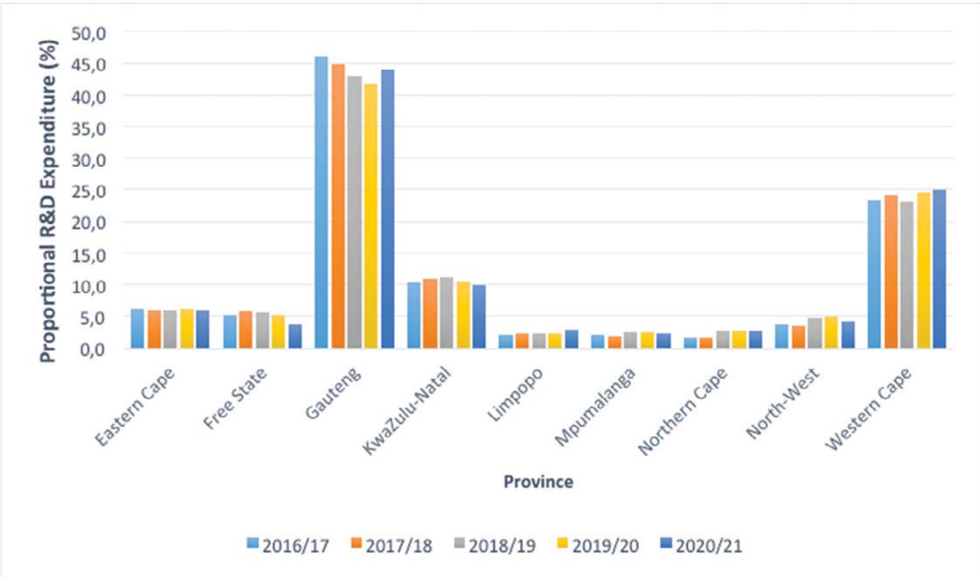


Figure 6.9: Proportion of R&D expenditure by province

Source: HSRC and DSI National Survey of Research and Experimental Development

To take the provincial sizes of the regional economies into consideration, research expenditure as a percentage of provincial GDP was calculated for the 2021 financial year and is depicted in **Figure 6.10**. Data shows that the Western Cape has the highest R&D intensity of 1,31 followed by Gauteng (0,93%). The provincial R&D intensity of Gauteng is well above the national R&D intensity of 0,64%.

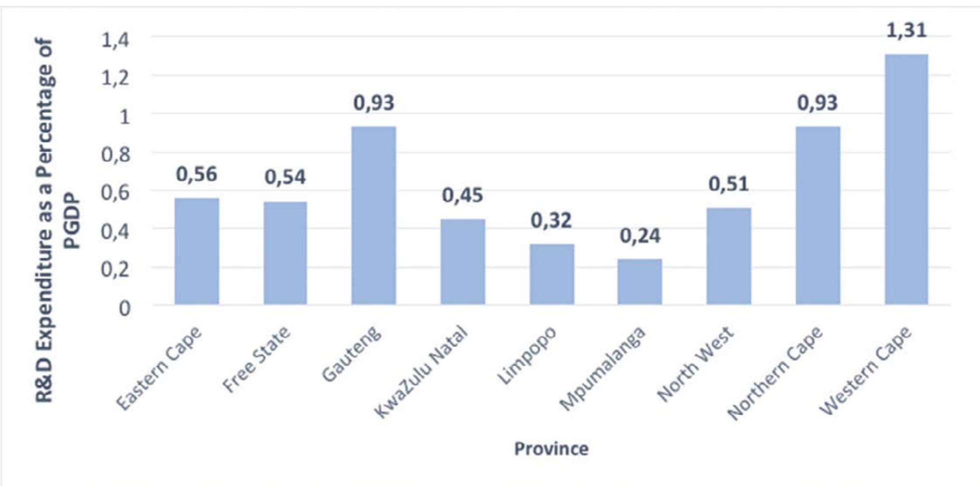


Figure 6.10: Provincial R&D expenditures as percentage of provincial GDP

Source: HSRC and DSI National Survey of Research and Experimental Development

Figure 6.11 depicts R&D expenditure per capita. The Western Cape has the highest investment in R&D per capita (R1 232), followed by Gauteng (R974). The remaining provinces have very low investment in R&D per resident.

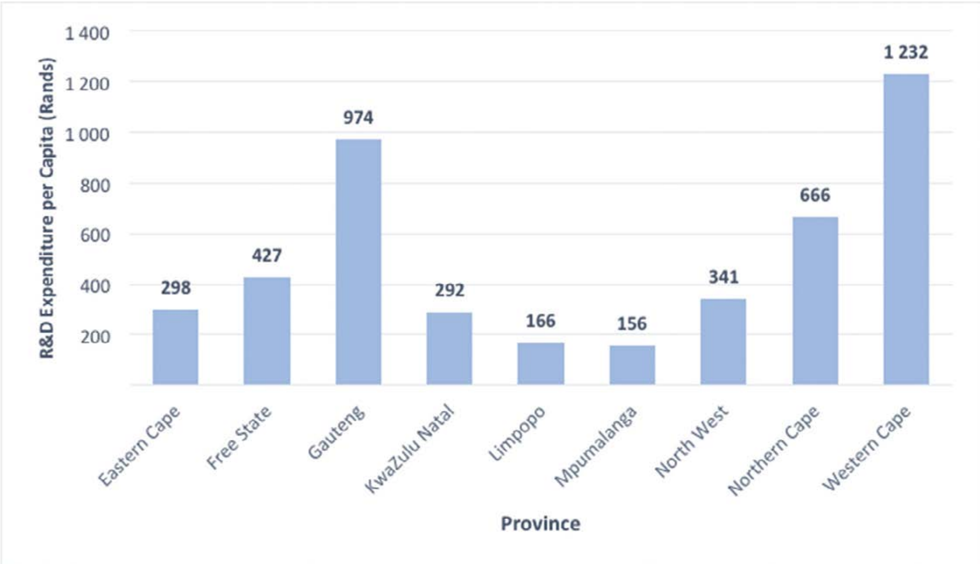


Figure 6.11: Provincial R&D expenditure per capita

Source: HSRC and DSI National Survey of Research and Experimental Development

Taken together, these findings show the vast disparity in R&D performance by the various provinces in South Africa. The Western Cape province has an R&D intensity that is much higher than the national figure of about 0,64%.

Table 6.16 shows business expenditure on R&D for each province between 2016/17 and 2020/21. The business sector in Gauteng performs the highest R&D (R5,6 billion in 2020/21). This was a slight improvement from R5,4 billion in the previous year. Business expenditure in the Western Cape also improved from R1,8 billion in 2019/20 to R1,9 billion in 2020/21. Overall, business expenditure in the provinces has not recovered to pre-Covid-19 levels.

Table 6.16: Business sector R&D expenditure by province

Province	2016/17	2017/18	2018/19	2019/2020	2020/21
	R' 000				
Eastern Cape	690 478	707 348	674 516	439 537	214 755
Free State	1 060 177	1 105 873	991 206	694 454	470 355
Gauteng	7 876 139	8 285 425	7 617 873	5 447 407	5 577 133
KwaZulu-Natal	1 553 130	1 679 718	1 446 281	1 193 914	821 492
Limpopo	171 567	223 014	184 199	78 484	199 637
Mpumalanga	284 655	304 990	392 986	370 695	256 575
North-West	526 962	565 486	601 653	566 308	526 476
Northern Cape	49 508	60 007	50 561	39 576	29 084
Western Cape	2 568 653	2 927 324	2 488 558	1 874 107	1 949 835
Total	**14 781 270**	**15 859 185**	**14 447 833**	**10 704 481**	**10 047 344**

Source: HSRC and DSI National Survey of Research and Experimental Development

This data shows that business expenditure has declined significantly in the Eastern Cape, Free State and KwaZulu-Natal.

Figure 6.12 illustrates the percentage proportional trend of business R&D expenditure among the provinces. The trend shows that business expenditure in R&D in Gauteng, the Free State and Limpopo declined slightly. The proportion of business expenditure in the rest of the provinces increased marginally. Despite the COVID-19 pandemic, overall business expenditure was stable.

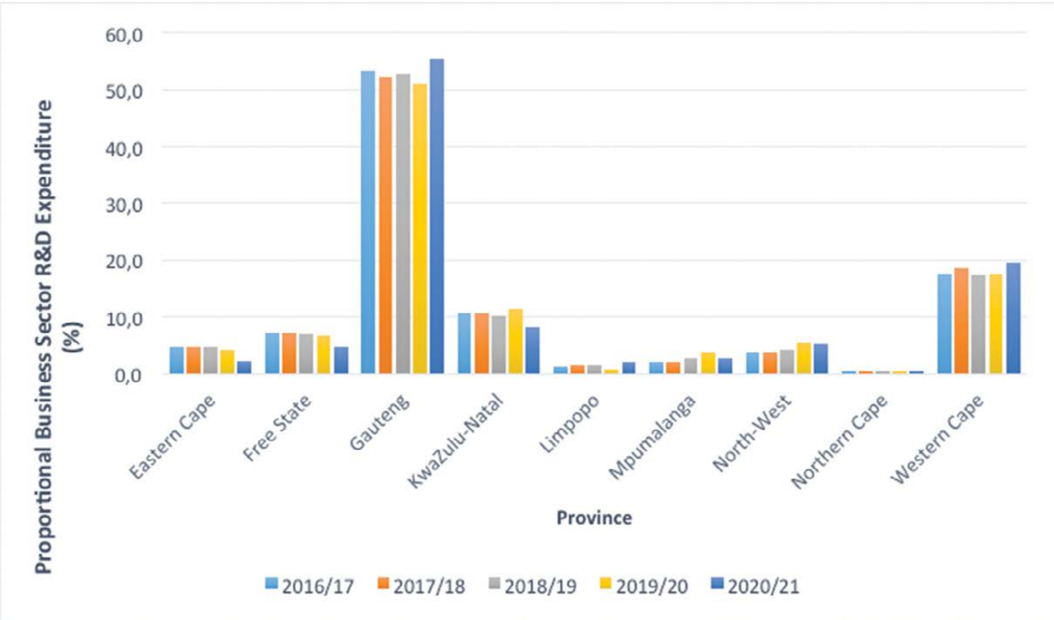


Figure 6.12: Proportional business sector R&D expenditure by province

Source: HSRC and DSI National Survey of Research and Experimental Development

Government supports R&D expenditure through various programmes and funding instruments. **Table 6.17** displays government expenditure among the provinces between 2016/17 and 2020/21.

Table 6.17: Government sector R&D expenditure by province

	2016/17	2017/18	2018/19	2019/2020	2020/21
	R'000				
Eastern Cape	222 456	281 201	305 629	301 816	383 648
Free State	81 957	81 890	59 694	45 660	51 714
Gauteng	885 142	974 192	836 827	581 945	626 239
KwaZulu-Natal	172 655	206 551	236 602	205 503	284 898
Limpopo	76 541	86 876	89 889	81 308	90 390
Mpumalanga	107 237	104 154	88 922	83 648	74 233
North-West	57 994	60 594	66 727	57 423	60 752
Northern Cape	66 200	94 659	88 575	52 5299	131 729
Western Cape	428 465	435 757	450 560	483 841	533 926
Total	**2 098 646**	**2 325 875**	**2 223 426**	**1 893 543**	**2 237 531**

Source: HSRC and DSI National Survey of Research and Experimental Development

As the data shows, Gauteng (R626 million) again has the highest expenditure, followed by the Western Cape (R533 million) and Eastern Cape (R383 million). An interesting finding is the significant increase of more than double in the Northern Cape, from R52 million in 2019/20 to R131 million in 2020/21.

Figure 6.13 shows that government's proportional expenditure in Gauteng declined from 30,7% in 2019/20 to 280% in 2020/21. During the same period, the proportional government expenditure in Western Cape also declined marginally from 25,6% to 23.9%. As the graph shows, the Eastern Cape and KwaZulu-Natal have enjoyed modest proportional increases. The proportional expenditure in the Eastern Cape rose from 15,9% in 2019/20 to 17,1% in 2020/21 and proportional expenditure in KwaZulu-Natal also increased from 10,6% in 2019/20 to 12,7% during this period.

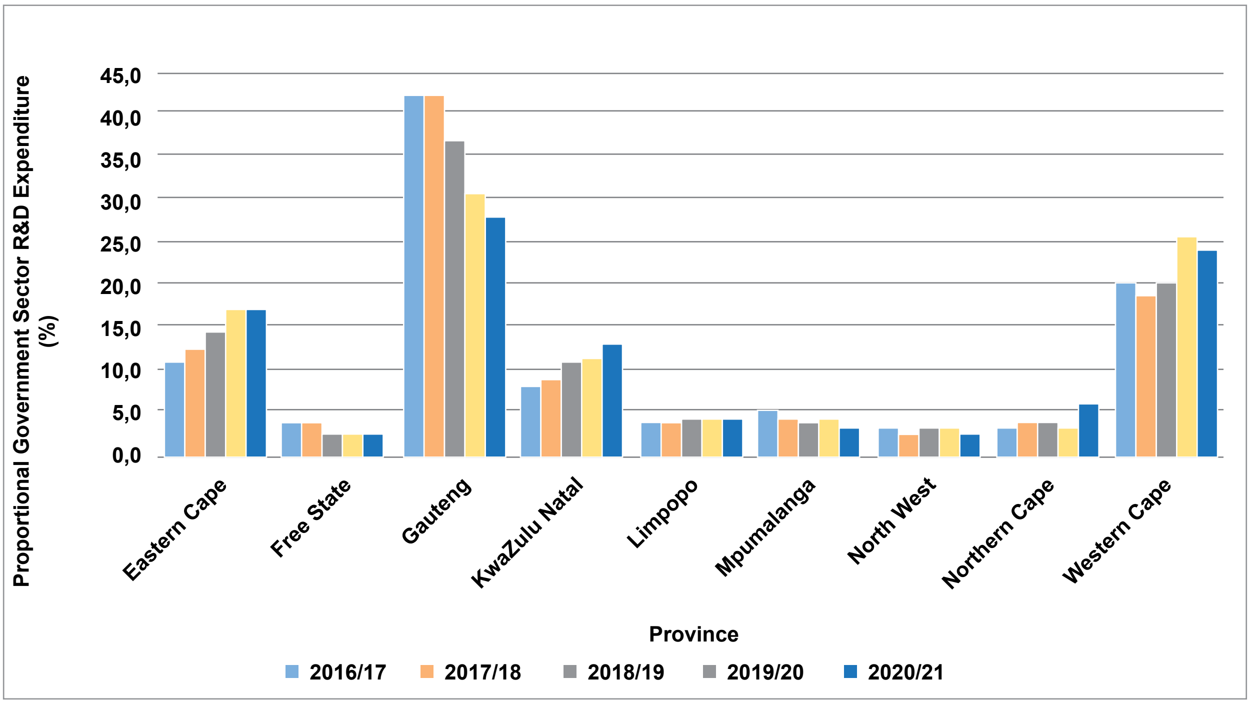


Figure 6.13: Proportional government sector R&D expenditure by province
Source: HSRC and DSI National Survey of Research and Experimental Development

At regional level, higher education institutions are key actors in the regional innovation system in stimulating innovation and economic development. The presence of universities that are strong R&D performers provides regions with access to knowledge assets and technological knowledge. The knowledge can be transferred to local businesses or start-ups can be created. The level of investment in research and development by the higher education sector in the provinces is displayed in **Table 6.18**.

The data in the table shows the Western Cape enjoys the highest expenditure (R4,7 billion in 20210/21) which is testimony to the high concentration of leading universities in the province. It can be argued that these universities are not only able to attract talent but are also able to attract domestic and international research funds. Gauteng is a close second (R4,4 billion) followed by KwaZulu-Natal with an expenditure of R1,4 billion.

Table 6.18: Higher education sector R&D expenditure by province

	2016/17	2017/18	2018/19	2019/20	2020/21
	R'000				
Eastern Cape	1 002 978	1 017 383	1 027 996	1 123 901	1 190 432
Free State	625 646	894 118	803 727	847 104	624 925
Gauteng	4 105 237	4 269 020	3 730 236	4 188 428	4 474 214
KwaZulu-Natal	1 157 722	1 428 653	1 646 915	1 514 301	1 377 646
Limpopo	301 809	358 543	384 346	466 703	540 991
Mpumalanga	148 981	155 430	170 553	213 914	220 654
North-West	469 171	449 196	833 635	856 833	555 118
Northern Cape	188 515	180 632	161 714	169 999	52 337
Western Cape	3 659 198	4 256 902	4 423 997	4 797 779	4 749 419
Total	**11 659 258**	**13 009 876**	**13 183 119**	**14 178 960**	**13 785 736**

Source: HSRC and DSI National Survey of Research and Experimental Development

As shown by the proportional R&D expenditure in **Figure 6.14**, the Western Cape's proportional expenditure was 34,5% in 2020/21; slightly higher than the 32,5% contribution from Gauteng. It is worth noting that Gauteng's portion has increased from 29,5%% in 2019/20 to 32,5% in 2020/21.

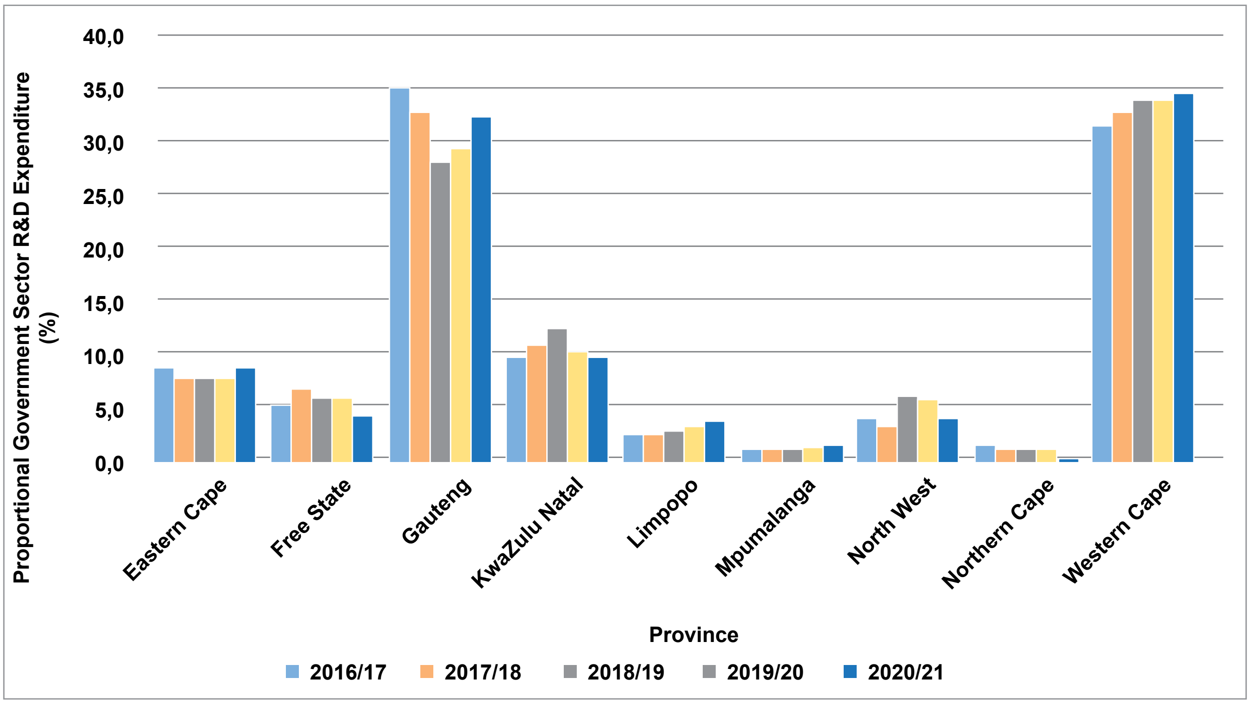


Figure 6.14: Proportional higher education sector R&D expenditure by province

Source: HSRC and DSI National Survey of Research and Experimental Development

6.3.4. Performance in Maths and Physical Science by province

This section presents the performance of the provinces in Mathematics and Physical Science in matric. As shown in **Table 6.19**, the percentage of learners who achieved 50% and above remains very low, especially in the Eastern Cape province and Limpopo. What is of concern is that the situation does not seem to be improving year on year.

Table 6.19: Performance in Maths by province

	% achieved at 30% and above			% achieved at 40% and above			% achieved at 50% and above		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Eastern Cape	39,7	46,6	46,1	23,6	28,0	28,1	13,6	16,0	16,0
Free State	66,3	66,6	64,6	42,7	42,8	41,1	25,2	25,0	24,6
Gauteng	65,4	68,2	62,7	45,9	48,3	44,4	30,5	31,7	28,9
KwaZulu-Natal	51,2	54,2	54,6	33,4	35,0	35,0	20,4	20,7	20,7
Limpopo	49,7	54,5	49,9	31,5	33,7	30,8	18,8	19,5	18,0
Mpumalanga	50,9	54,0	52,8	33,4	34,7	34,3	20,6	20,6	20,5
North West	63,4	71,5	59,9	42,1	47,7	37,9	25,7	28,5	22,3
Northern Cape	55,3	59,2	51,5	34,9	39,1	32,6	21,2	23,2	20,0
Western Cape	71,6	73,4	67,9	54,4	54,5	51,6	39,8	39,1	37,8
National	53,8	57,6	55,0	35,6	37,6	36,0	22,3	23,0	22,0

Source: Department of Basic Education, 2023

Table 6.20 displays trends in performance of learners in Physical Science. The performance in this subject is also very low, especially when considering the percentage of learners who achieved 50% and above. The Western Cape is by far the best performing province (45%) and its performance has been improving gradually. Again, the Eastern Cape is the lowest performer despite the slight improvement.

Table 6.20: Performance in Physical Science in provinces

	% achieved at 30% and above			% achieved at 40% and above			% achieved at 50% and above		
	2020	2021	2022	2020	2021	2022	2020	2021	2022
Eastern Cape	55,6	62,3	70,5	32,3	37,4	43,9	18,2	21,2	24,8
Free State	71,2	75,1	80,6	45,0	48,1	53,7	26,2	28,9	32,0
Gauteng	72,6	73,5	76,7	50,2	51,0	53,3	33,5	34,1	34,9
KwaZulu-Natal	69,7	71,2	77,3	46,0	47,0	53,1	28,2	28,3	32,2
Limpopo	63,0	67,8	73,3	38,3	41,6	46,1	22,4	23,8	26,9
Mpumalanga	60,0	61,5	68,1	37,9	38,5	45,6	22,9	22,6	27,7
North West	68,5	77,5	77,3	42,2	50,4	49,2	25,5	29,4	28,6
Northern Cape	53,4	65,2	69,5	32,0	42,4	42,2	20,2	24,1	25,1
Western Cape	76,2	78,3	81,1	57,5	59,7	61,4	42,9	44,5	45,2
National	65,8	69,0	74,6	42,4	44,8	49,7	26,3	27,3	30,4

Source: Department of Basic Education, 2023

6.3.5. Access to internet

ICT is a key enabler in economic and social development. Access to ICT makes it easier for people to access information, connect to business and improve productivity. It is also critical for education as it provides students with access to knowledge and educational resources.

Figure 6.15 compares access to the internet across all nine provinces. According to the data, access to the internet using all available means was highest in the Western Cape (89,1%), Gauteng (86,7%) and Mpumalanga (76,6%). The provinces that had the lowest access were Limpopo (63,7%) and the Eastern Cape (64,7%).

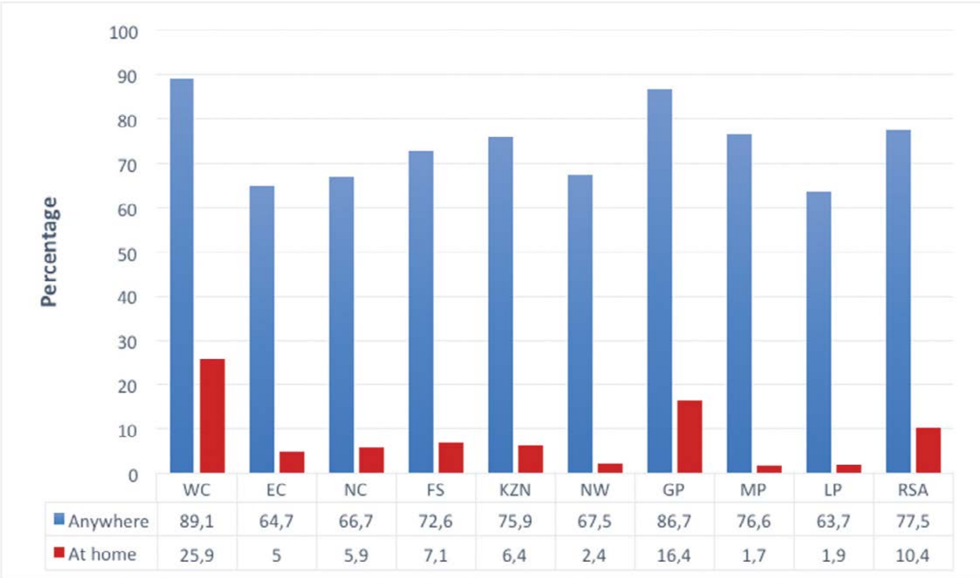


Figure 6.15: Percentage of access to internet across provinces
Source: General Household Survey, 2021

The data shows low levels of access to the internet at home across all provinces. The provinces with the highest access to internet at home are the Western Cape (25,9%) and Gauteng (16,4%), which are the most prosperous provinces. The disparity in access to the internet at home is striking and reveals the vast social and economic inequality between provinces.

6.3.6. Government innovation-support organisations

To support innovation throughout the country, government has invested in innovation-support organisations in various provinces. These organisations are intermediary organisations that provide innovation infrastructure and support services, especially to SMMEs and previously marginalised communities. The overall purpose of these organisations is to improve the success of SMMEs and start-ups.

As shown in **Table 6.21**, these organisations include technology stations, incubators, living labs and fabrication labs. The technology stations and incubators are the main support instrument organisations.

Table 6.21: Number and type of innovation-support organisations in provinces

	Eastern Cape	Free State	Gauteng	KwaZulu-Natal	Limpopo	Mpumalanga	Northern Cape	North West	Western Cape	Total
Technology Stations	3	2	5	2	1	0	1	0	3	17
Incubators	8	5	22	11	5	7	3	2	7	70
Science parks	1	1	1		0	0	0		1	4
Fab Labs	2	1	2		1		1	1	1	9
Living Labs	2	1	0	3	0	0	1	2	1	10
Ekasi Labs			10							10
Innovation -Colab				1						1
University-based incubators	2	2	4	1					2	11
mLab				1						1

The technology stations are supported by the DSI and are implemented by the TIA. They are sector-focused and are located at universities and universities of technology. They facilitate technology transfer between these educational institutions and small enterprises. One of their key contributions is to expose students and university staff members to the needs of industry, especially small enterprises.

The Small Enterprise Development Agency incubator programme (under the Department of Small Business Development) remains the largest innovation-support programme with a broad national footprint. It not only provides innovation infrastructure to industry, but also provides training and facilitates linkages between the actors in the innovation ecosystem.

A recent development has been the emergence of a new breed of university-based incubator, which are a variant of the traditional business incubator. One of its key functions is to promote technological transfer and commercialisation. There has also been an increase in the number of living labs from four in 2021 to 11 in 2022.

The data shows the uneven distribution of these organisations as primarily located in Gauteng, Western Cape and Eastern Cape.

6.3.7. Impact on employment

Information on output indicators such as publications, patents and innovative products and services is not available in South Africa at provincial level. Because of these limitations, this report resorted to comparing employment in low, medium and high-technology manufacturing sectors at provincial level. To classify the industrial sectors in terms of R&D intensity, the 2001 OECD classification was adopted.

Employment in high-tech manufacturing industries

The share of employment in high-technology manufacturing sectors is an indicator of the manufacturing economy that is based on continual innovation through creative, inventive activity. High-tech sectors and enterprises are key drivers of economic growth and productivity, and generally provide high value-added and well-paid employment.

Table 6.22 shows employment levels in high technology manufacturing industry between 2012 and 2018 at the provincial level. According to the data that was used, the high-technology sector includes radio, TV, instruments, watches and clocks.

Table 6.22: Provincial employment in high-technology sectors

	Year		Change in employment	% Change
	2012	2021		
Eastern Cape	948	872	-76	-8,01
Free State	502	552	50	9,96
Gauteng	10 842	11 968	1 126	10,38
KwaZulu-Natal	2 674	2 797	123	4,59
Limpopo	474	531	57	12,02
Mpumalanga	677	742	65	9,60
Northern Cape	160	236	76	47,5
North West	508	519	11	2,16
Western Cape	3 522	3 803	281	7,97

Source: Quantec

The data shows that, between 2012 and 2021, employment in high-technology sectors increased in all the provinces except for the Eastern Cape. In 2021, Gauteng had the highest employment in high technology sectors(11 956) followed by the Western Cape (3 803) and KwaZulu-Natal (2 797). The rest of the provinces have very low employment levels in this sector, which could be a result of their low R&D expenditures and economic structures that are dominated by primary industries.

Figure 6.16 illustrates the trends in employment in the high-technology industrial sector graphically. The figure shows that employment patterns in high-technology sectors has not changed significantly at provincial level, especially in provinces that have higher R&D expenditures.

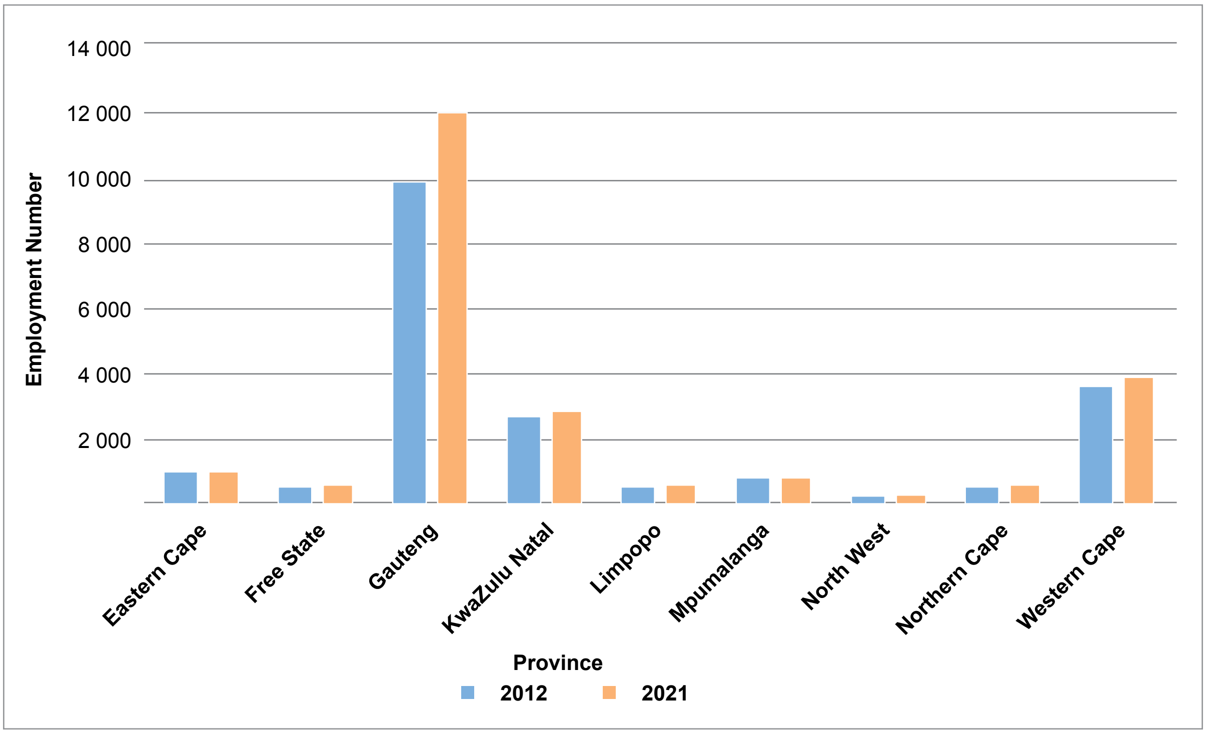


Figure 6.16: Employment in high-tech manufacturing at provincial level

It must be noted that the data from Quantec excludes employment data from aircraft and equipment, pharmaceuticals, medical, precision, and optical instruments that are regarded as high-technology sectors. Therefore, employment in this category might be under-represented.

Employment in medium-tech manufacturing industries

Table 6.23 shows employment in medium-tech industries that includes medium-high technology and medium-low technology industries.

The data reveals that, in all the provinces, there has been a decline in provincial employment in this sector. The provinces that experienced the highest decline are the North West (-21,45%) and the Eastern Cape (-20,65%). Mpumalanga (-2,14%) and the Free State (-5,48%) experienced the lowest declines compared to other provinces.

Table 6.23: Provincial employment in medium-technology sectors

	Number of employment		Difference in employment	% change
	2012	2021		
Eastern Cape	59 524	52 367	-7 157	-12,02
Free State	28 817	27 164	-1 653	-5,73
Gauteng	34 991	32 064	-25 037	-8,36
KwaZulu-Natal	130 644	119 882	-10 762	-8,23
Limpopo	29 710	26 081	-3 629	-12,21
Mpumalanga	49 103	47307	-1 796	-3,65
Northern Cape	12 140	10 773	-1 367	-11,26
North West	39 157	31 212	-7 945	-20,29
Western Cape	109 567	106 875	-2 692	-12,02

Figure 6.17 illustrates the trends in employment in employment in medium-technology sectors graphically. The graph illustrates that KwaZulu-Natal is the highest employer, followed by the Western Cape and Eastern Cape.

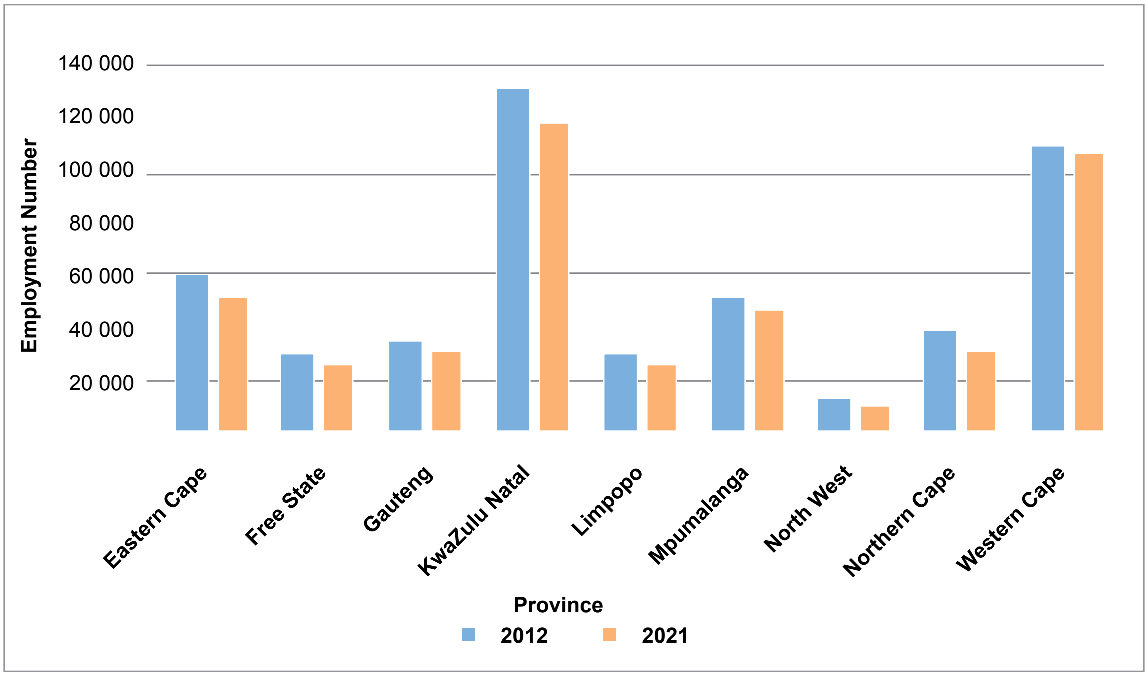


Figure 6.17: Employment in medium-technology manufacturing sectors

Employment in low-technology manufacturing sectors

Table 6.24 displays employment in low-technology sectors. The data shows that Gauteng is the largest employer in this category followed by KwaZulu-Natal and Western Cape.

Table 6.24: Employment in low-technology sectors

Province	Number of employment		Difference in employment	% Change
	2012	2021		
Eastern Cape	41 605	37 568	-4 037	-9,70
Free State	28 092	25 982	-2 110	-7,51
Gauteng	193 361	184 198	-9 163	-4,73
KwaZulu-Natal	153 352	132 858	-20 494	-13,36
Limpopo	29 731	26 706	-3 025	-10,17
Mpumalanga	42 840	36 083	-6 757	-15,77
Northern Cape	6 724	6 761	37	0,55
North West	27 578	27 988	410	1,48
Western Cape	133 264	119 785	-13 479	-10,11

Source: Quantec

As illustrated in Figure 6.18, there has been a significant decline in employment across the board, except for the Northern Cape and Northwest provinces.

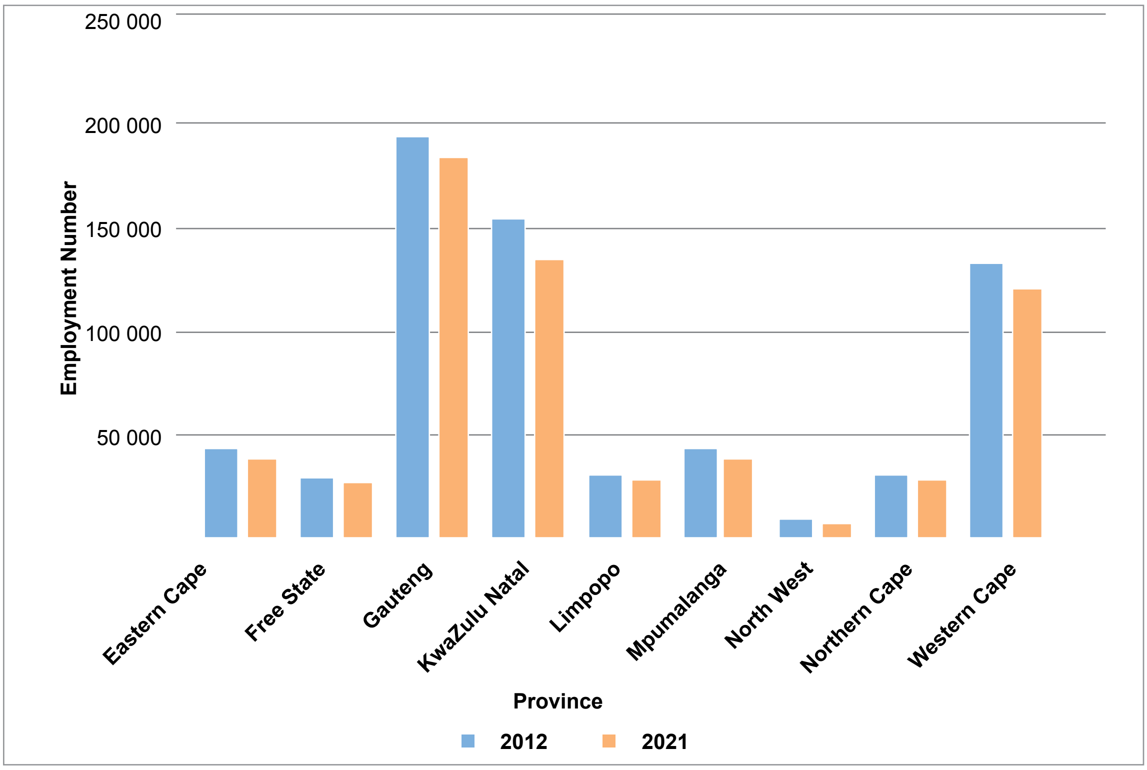


Figure 6.18: Employment in medium-tech manufacturing sectors

To summarise, between 2012 and 2021, there has been an increase in high-technology employment in all the provinces except in the Eastern Cape and Western Cape. However, it must be noted that these increases are from a low base. On the other hand, employment in medium-technology sectors declined in all the provinces. Similarly, except for the Northern Cape and North West, employment in low-technology sectors has also declined.

These findings show that at provincial level, despite the decline in employment, the medium and low-tech industries are still by far the largest employers. Decline in employment in these industries should be cause for concern, considering that most provincial economies are specialised in medium and low-tech activities.

None of the provinces have increased employment in high-technology sectors, which are regarded as key to regional economic development and competitiveness in a knowledge-driven economy. What is encouraging is that these sectors have not experienced job loses, although they are still very small contributors to provincial employment.

ANNEXURE A: RESEARCH COLLABORATIONS BY MAIN RESEARCH FIELD

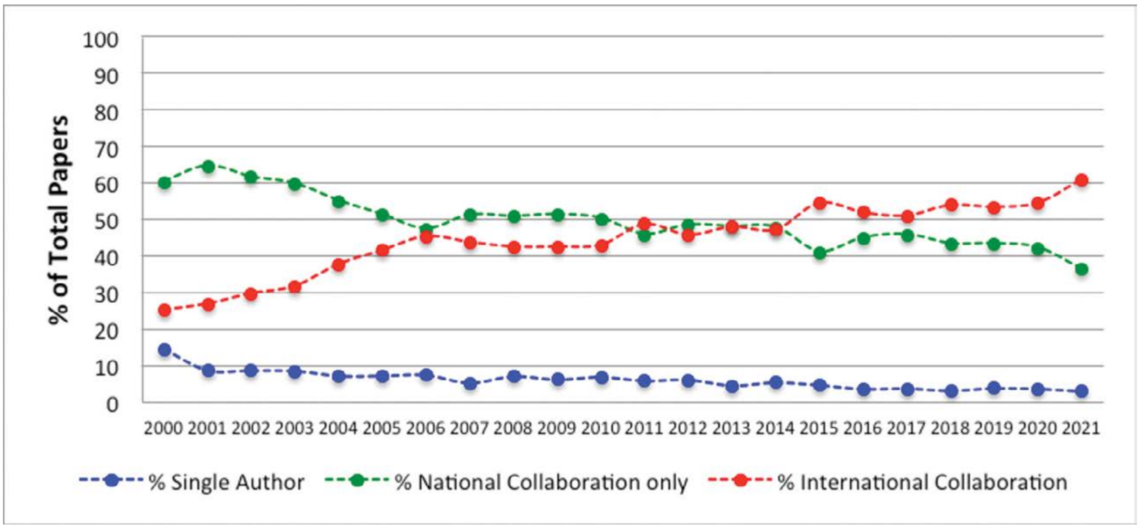


Figure A1: South African publication collaboration profiles in Agricultural Sciences

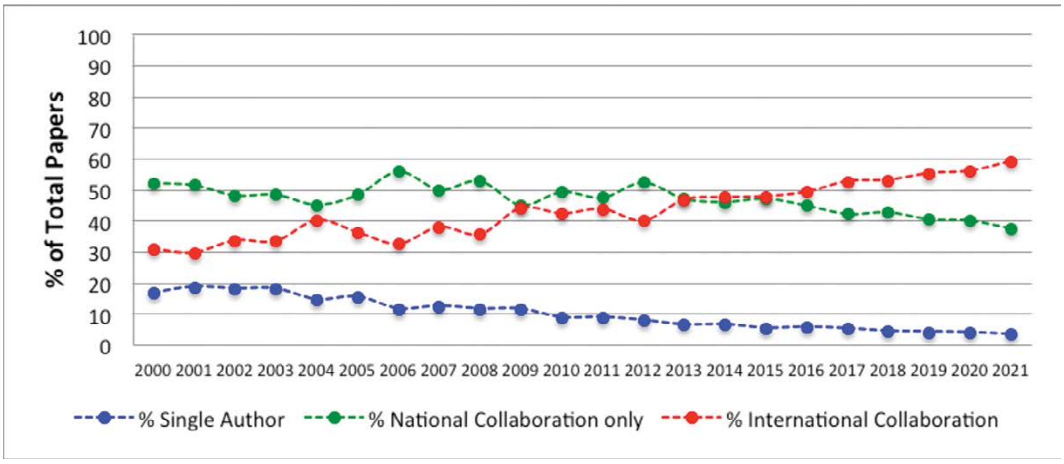


Figure A2: South African publication collaboration profiles in Engineering

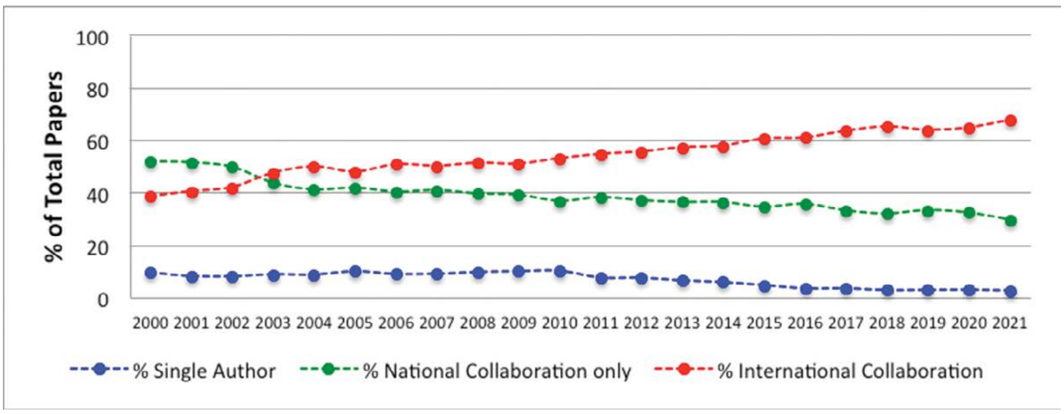


Figure A3: South African publication collaboration profiles in Health Sciences

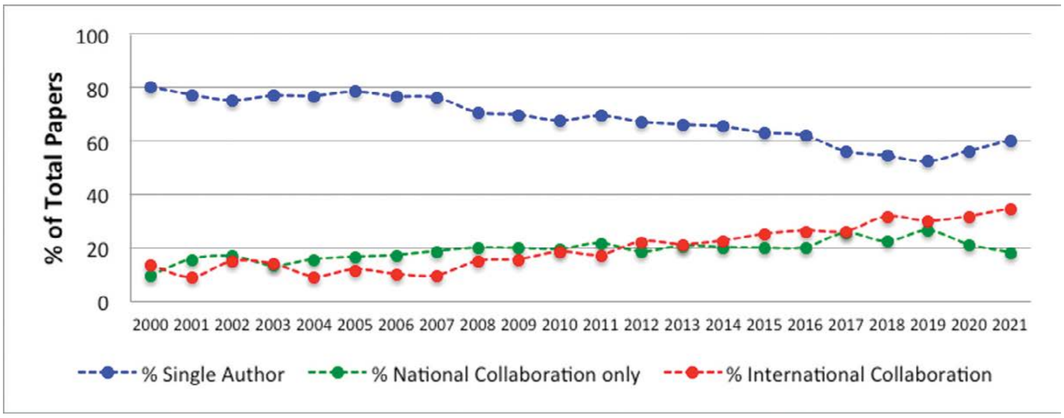


Figure A4: South African publication collaboration profiles in Humanities and Arts

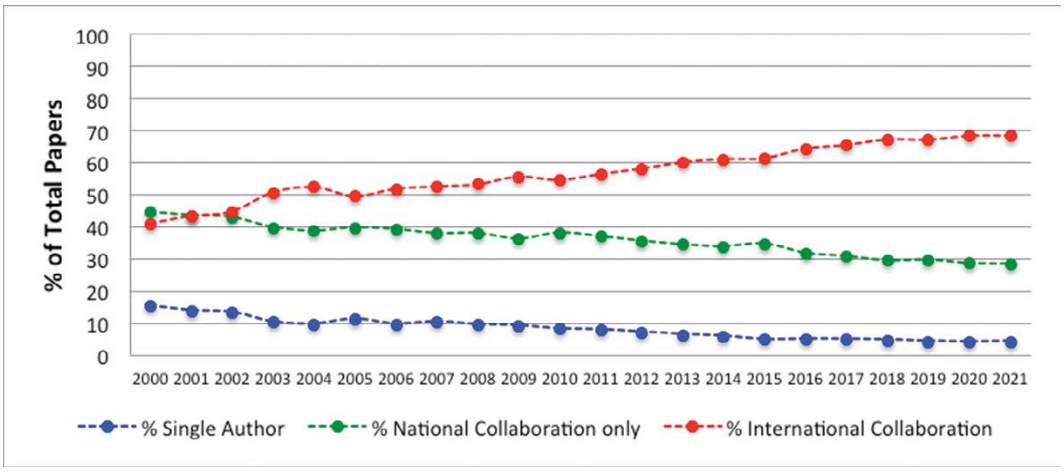


Figure A5: South African publication collaboration profiles in the Natural Sciences

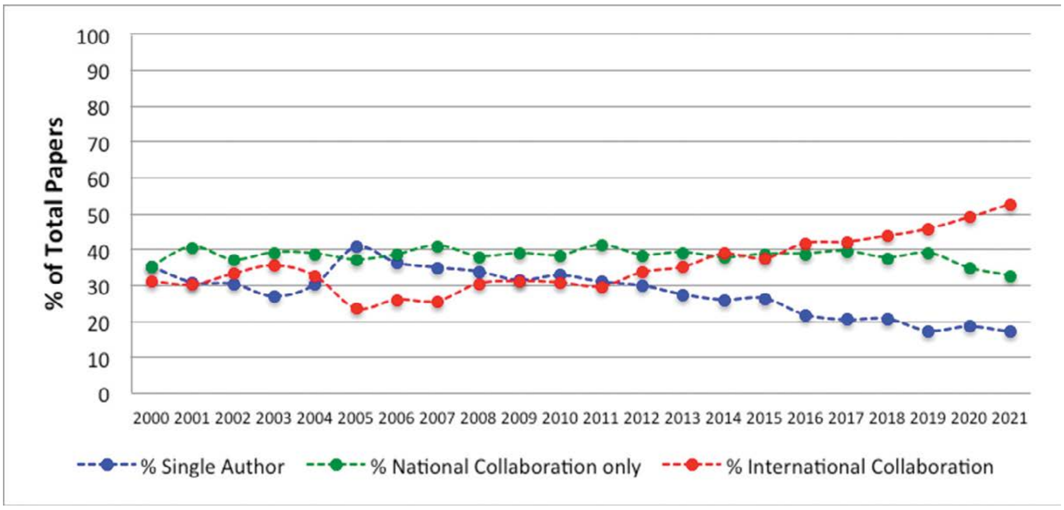


Figure A6: South African publication collaboration profiles in the Social Sciences

ANNEXURE B: TOP CITATION PERCENTILE INTERVALS PER FIELD

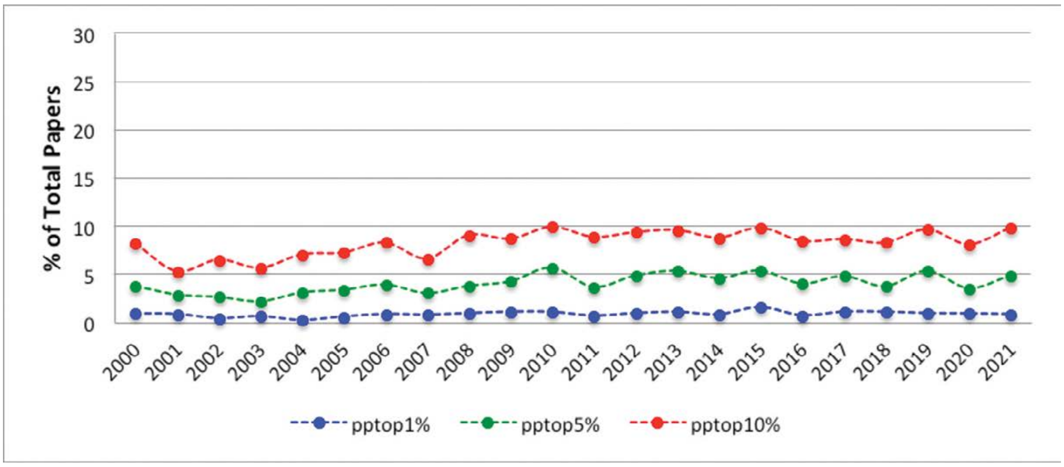


Figure B1: Proportion of South African publications in the Agricultural Sciences in the top citation percentile intervals

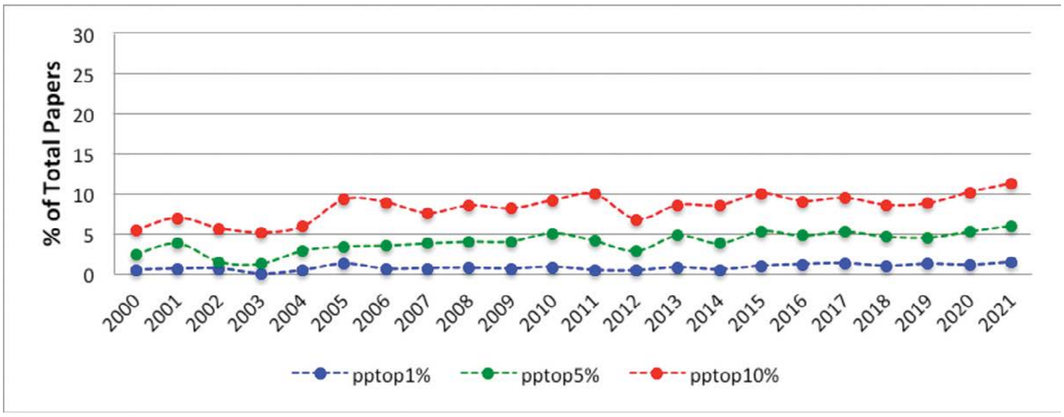


Figure B2: Proportion of South African publications in Engineering Sciences in the top citation percentile intervals

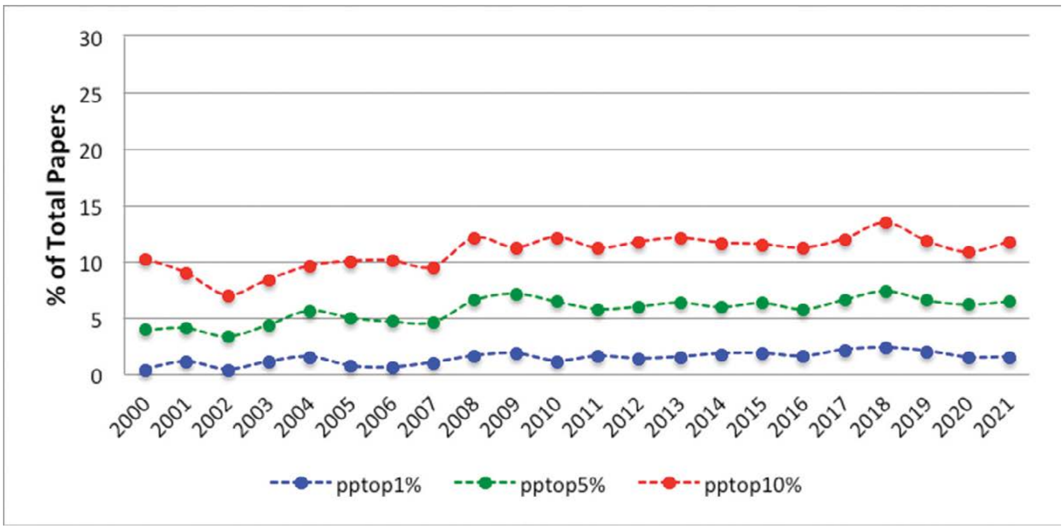


Figure B3: Proportion of South African publications in Health Sciences in the top citation percentile intervals

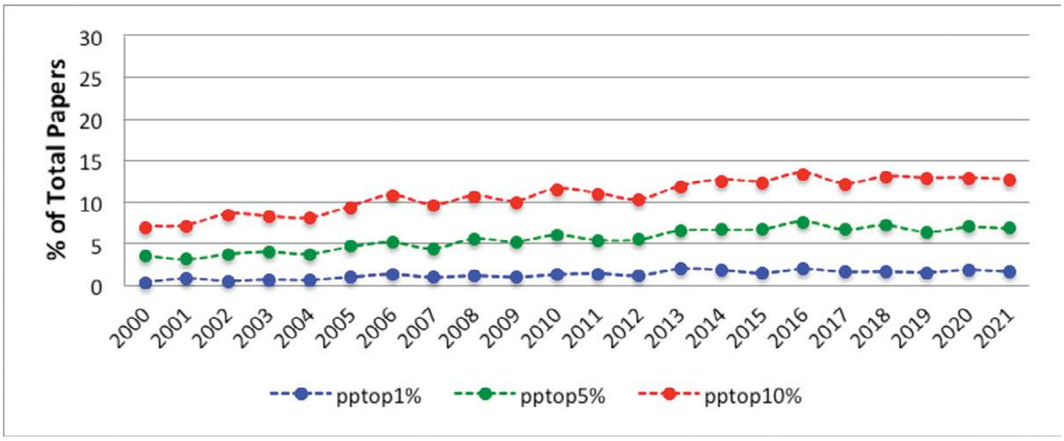


Figure B4: Proportion of South African publications in the Natural Sciences in the top citation percentile intervals

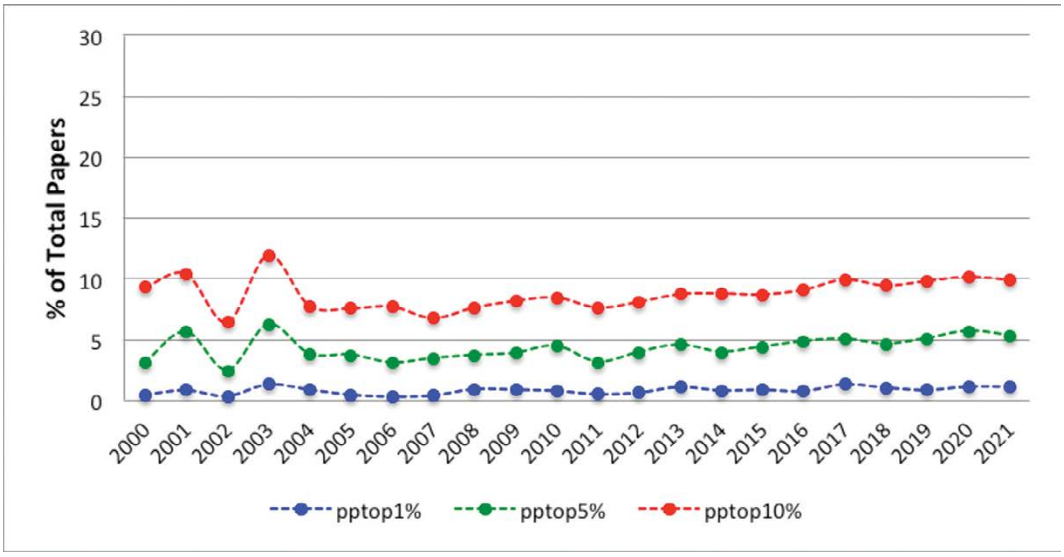


Figure B5: Proportion of South African publications in the Social Sciences in the top citation percentile intervals

DEPARMENT OF SCIENCE AND INNOVATION

NATIONAL ADVISORY COUNCIL ON INNOVATION

Suite L2, Enterprise Building

Mark Shuttleworth Street

The Innovation Hub

Pretoria

0087

Tel: 012 844 0925

E-mail: naci@dst.gov.za