2021

SOUTH AFRICAN SCIENCE, TECHNLOGY AND INNOVATION INDICATORS REPORT

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NACI
NATIONAL ADVISORY COUNCIL ON INNOVATION

2021

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NATIONAL ADVISORY COUNCIL ON INNOVATION

The 2021 South African Science, Technology and Innovation Indicators Report has been 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. Please email such comments and suggestions to naci@dst.gov.za.

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LIST OF ACRONYMS

4IR	Fourth Industrial Revolution
ARC	Agricultural Research Council
ARV	Antiretroviral (drug)
BERD	Business Expenditure on Research and Development
BRICS	Brazil, Russia, India, China and South Africa
CAGR	Compound Annual Growth Rate
CIPC	Companies and Intellectual Property Commission
CSIR	Council for Scientific and Industrial Research
CWTS	Centre for Science and Technology Studies
DBE	Department of Basic Education
ECSA	Engineering Council of South Africa
EIS	European Innovation Scoreboard
EPO	European Patents Office
EU	European Union
FDI	Foreign Direct Investment
FET	Further Education and Training
FTE	Full-time Equivalent
GDP	Gross Domestic Product
GEM	Global Entrepreneurship Monitor
GERD	Gross Domestic Expenditure on Research and Development
GII	Global Innovation Index
GVA	Gross Value Added
HDI	Human Development Index
HE	Higher Education
HEMIS	Higher Education Management Information System
HIV	Human Immumodeficiency Virus
ICD	International Classification of Diseases
ICT	Information and Communication Technology
IEB	Independent Examination Board
IMD	International Institute for Management Development
IP	Intellectual Property
IRP	Integrated Resource Plan
MTSF	Medium-term Strategic Framework
NACI	National Advisory Council on Innovation
NDP	National Development Plan
NEP	National Equipment Programme
NPO	Not-for-Profit Organisation
NRDS	National Research and Development Strategy
NRF	National Research Foundation
NSC	National Senior Certificate
NSI	National System of Innovation
PCT	Patent Cooperation Treaty
PPP	Purchasing Price Parity
R&D	Research and Development
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SEDA	Small Enterprise Development Agency
SET	Science, Engineering and Technology
SMME	Small, Medium and Micro Enterprises
SPI	Social Progress Index
STEM	Science, Technology, Engineering and Mathematics
STI	Science, Technology and Innovation
TB	Tuberculosis
TEA	Total Early-stage Entrepreneurial Activity
TIA	Technology Innovation Agency
TIMSS	Trends in International Mathematics and Science Study
TPP	Technology Platforms Programme
TRL	Technology Readiness Level
TSP	Technology Stations Programme
TVET	Technical and Vocational Education and Training
UK	United Kingdom
UN	United Nations
USA	United States of America
USPTO	United States Patent and Trademark Office
VC	Venture Capital
WHO	World Health Organisation

FOREWORD BY THE CHAIRPERSON

The National Advisory Council on Innovation (NACI) is pleased to release the 2021 Science, Technology and Innovation (STI) Indicators Report within the context of the rampant COVID-19 pandemic, deepening socioeconomic development crises and STI policy renewal, including the development of a new Decadal Plan. In future, once data is available, it will be possible to reflect on the impact of the National System of Innovation (NSI) and how it responded to the pandemic. The results of the NACI-led review of the National Research and Development Strategy (NRDS) and Ten-Year Innovation Plan and Foresight Exercise provide important input into the development of the new Decadal Plan for STI.

The STI Indicators Report highlights both progress and lack thereof in respect of selected indicators. The NSI's pipeline challenges persist, despite numerous government interventions. According to the 2019 Trends in International Mathematics and Science Study (TIMSS), the country's average scores are below the minimum benchmark level of 400 for both Mathematics and Science in Grade 5 (374 and 324, respectively) and Grade 9 (389 and 370, respectively). The pass rate declined for all the science, technology, engineering and mathematics (STEM)-related subjects, except for Mathematical Literacy, in which there was a slight increase in the percentage of learners passing with 30% and more (from 80.6% in 2019 to 80.8% in 2020). NACI has initiated a study, the outcome of which may explain the persisting problem.

The 2019 White Paper on STI set the target of 1.5 growth expenditure as a percentage of gross domestic expenditure on research and development (GERD). The current GERD stands at 0.83%. Over the last decade, business expenditure on research and development (BERD) has stagnated at around R10.5 billion (2010 constant values) before dropping to R9.3 billion in 2018/19. Consequently, the BERD, as a share of GERD, has been declining (from 53.2% in 2009/10 to 39.3% in 2018/19).

For a long time, the research system has been productive relative to its size. There is a concern that South Africa could be losing its leadership position in the rest of the African continent. For the first time, Egypt appears to be producing more publications than South Africa during 2018 (13 327 vis-à-vis 13 009).

South Africa's share of patents at the United States Patent and Trademark Office (USPTO) is low and has generally been slowly declining (from 0.060% in 2016 to 0.051% in 2019). Receipts from the sale of intellectual property (IP) in South Africa have grown at a slower rate than for comparable countries, and declined by 10% in 2019.

There was a small increase (4.6%) in the output of high- and medium-technology manufacturing in 2019, compared with the previous year. However, the share of high- and medium-technology manufacturing in total manufacturing was marginally lower in 2019 (29.36%) than in 2009 (26.95%). In comparison with the previous year, the value of South Africa's high-technology exports declined by 10% in 2019. Service exports have similarly tended to decline and were almost 8% lower than in 2018. The share of overall manufacturing employment for medium- and high-technology sectors rose from 28.5% (2009) to 32.31% (2019).

We thank Dr P Letaba, Dr D Kaplan, Dr M Kahn, Prof A Pouris and Dr M Madikizela for providing technical and intellectual support to the production of the report.

We hope the STI Indicators Report will serve as a resource to policy makers, researchers, civil society, students and everyone in and outside the NSI. There is a need for complementary studies to deepen our understanding of certain trends and factors.

Dr Shadrack Moephuli
NACI Chairperson

1. EXECUTIVE SUMMARY

1.1 Revised conceptual framework

The conceptual framework for the 2021 South African Science, Technology and Innovation Indicators Report (Figure 1.1) utilises the revised South African Innovation Scorecard framework. This is adapted from the European Innovation Scoreboard.

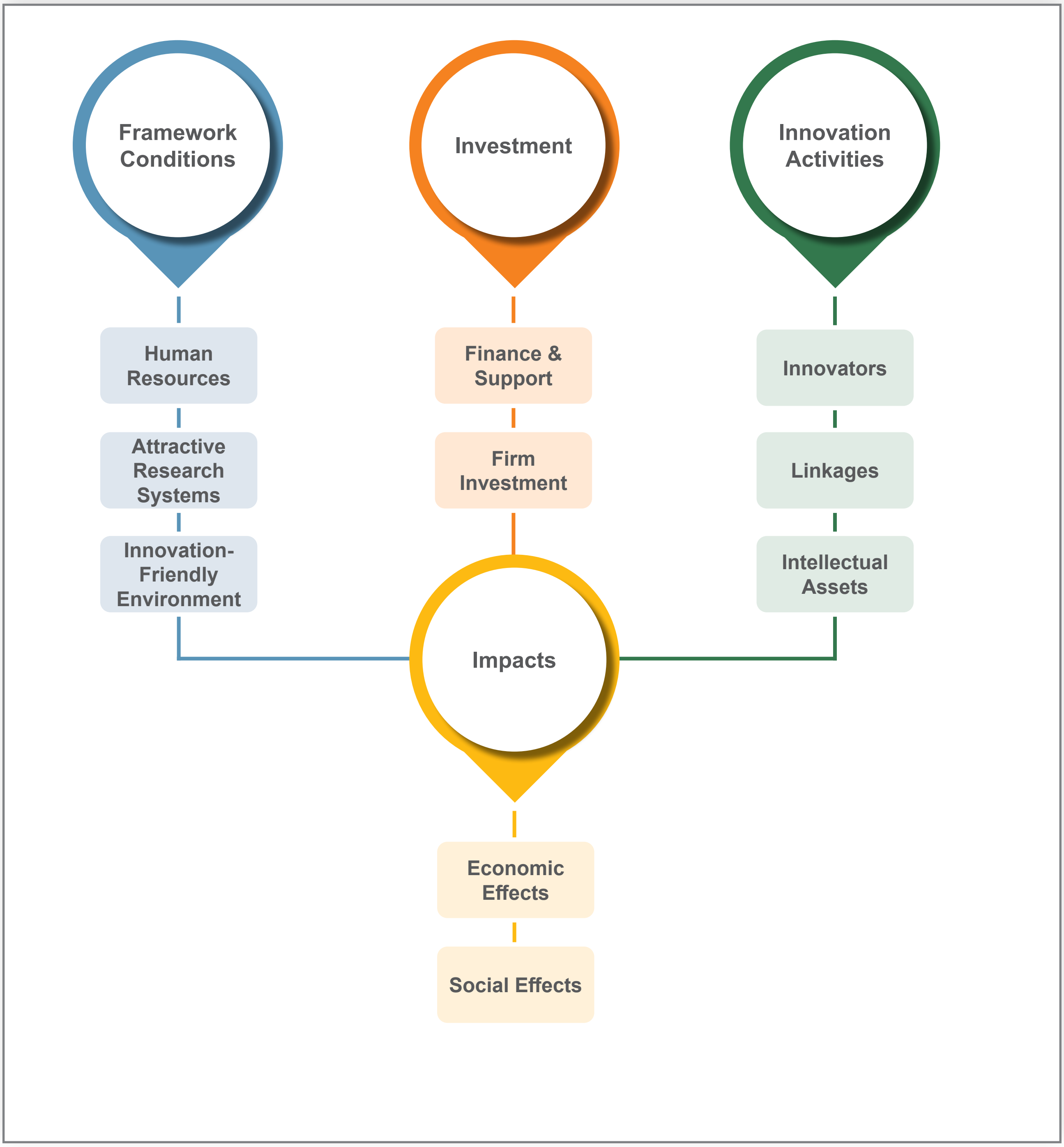


Figure 1.1: Revised South African Innovation Scorecard Framework

The Framework Conditions replaces the Enablers in the previous framework, in which the STI funding and support component is replaced by the Innovation-Friendly Environment (broadband penetration and entrepreneurship). A new pillar of Investment brings together STI finance and support, and firm investment. A main factor behind the adoption of this new framework is the separation of investment and innovation activities, hence the inclusion of another new pillar, Innovation Activities. The Impacts pillar was previously named STI Outputs. The linkages are not incorporated as part of the 2021 report and will be included in future.

1.2 Key highlights

1.2.1 Innovation framework conditions

- The proportion of both enrolments and graduates in science, engineering and technology (SET) is steady at around 30% of the total. The Ten-Year Innovation Plan set a target of 35% for SET graduates by 2018.

- The country's average scores on the 2019 Trends in International Mathematics and Science Study are below the minimum benchmark level of 400 for both Mathematics and Science in Grade 5 (374 and 324, respectively) and Grade 9 (389 and 370, respectively).

- COVID-19 had a negative impact on the performance of the 2020 National Senior Certificate (NSC) cohort. The pass rate declined for all the STEM-related subjects, except for Mathematical Literacy, in which there was a slight increase in the percentage of learners passing with 30% or more (from 80.6% in 2019 to 80.8% in 2020).

- For the first time, in 2018, Egypt, appeared to be producing more publications than South Africa (13 327 vis-à-vis 13 009).

- South Africa has the biggest Specialisation Index in social sciences (2.86). Australia, Nigeria and the USA emphasise social sciences too, but to a lesser extent.

1.2.2 STI investments

R&D INTENSITY

- Although the country's research and development (R&D) intensity and GERD as a percentage of GDP in 2009 was nearly double that of Egypt, in 2018, Egypt had an R&D intensity of 0.72% vis-à-vis 0.75% for South Africa. The country's R&D intensity decreased from 0.83% in 2017.

NRF GRANTS CLAIMED

- There was a significant 18.1% decline in the National Research Foundation (NRF) grants claimed from 2019 to 2020.

TOP BENEFICIARIES OF RESEARCH INFRASTRUCTURE: PHYSICAL AND CHEMICAL SCIENCES

- Physical sciences and chemical sciences remain the major beneficiaries of research infrastructure support through the National Equipment Programme (NEP) (a share of 38.0% and 28.6%, respectively, in 2020).

SIGNIFICANT TIA PROJECT EXPENDITURE: BIO-ECONOMY

- A significant amount of the Technology Innovation Agency (TIA)'s project expenditure in 2019/20 went to the bio-economy portfolio (R187 million, or 41.7%). The Technology Platforms Programme contributes a large share of the expenditure within this portfolio (44.7% in 2019/20 and 57.6% in 2018/19).

BERD AS A SHARE OF GERD

- Over the last decade, BERD has stagnated at around R10.5 billion (2010 constant values) before dropping to R9.3 billion in 2018/19. Consequently, BERD, as a share of GERD, has been declining (from 53.2% in 2009/10 to 39.3% in 2018/19).

R&D EXPENDITURE ON MEDICAL AND HEALTH SCIENCES

- There is a notable strong rise of R&D expenditure in medical and health sciences, where the percentage share of expenditure has more than doubled from 9.8% in 2001/02 to 21.2% in 2018/19.

15%
VENTURE CAPITAL INVESTMENTS

- Over the last decade, there has been a steady increase in the value of venture capital (VC) investments. The value of venture capital investments increased by 15% (nominal) in 2019 in comparison with the previous year.

1.2.3 Innovation activities

9–12.1% SOUTH AFRICAN PATENTS CIPC

- During 2008–2018, South African applicants received between 9% and 12.1% of the total patents awarded by the Companies and Intellectual Property Commission (CIPC).

SOUTH AFRICAN EPO PATENTS

- The number of South African patents granted at the European Patents Office (EPO) has fluctuated, but was marginally lower in 2019 (69) than in 2016 (70).

SHARE OF USPTO PATENTS

- South Africa's share of patents at the USPTO is low and has generally been slowly declining (from 0.060% in 2016 to 0.051% in 2019).

1.2.4 Innovation impact

HIGH- AND MEDIUM-TECH MANUFACTURING

- There was a small increase (4.6%) in the output of high- and medium-technology manufacturing in 2019 compared with the previous year. However, the share of high- and medium-technology manufacturing in total manufacturing was marginally lower in 2019 (29.36%) than in 2009 (26.95%).

VALUE OF HIGH-TECH EXPORTS

- In comparison with the previous year, the value of South Africa's high-technology exports declined by 10% in 2019. Service exports have similarly tended to decline and were almost 8% lower than in 2018.

REVENUE FROM IP SALES

- Receipts from the sale of IP have grown at a slower rate than for comparable countries, and declined by 10% in 2019.

EMPLOYMENT IN HIGH- AND MEDIUM-TECH

- The share of overall manufacturing employment for medium- and high-technology sectors rose from 28.5% (2009) to 32.31% (2019).

STANDARD OF LIVING

- Both the Social Progress Index (SPI) and the Human Development Index (HDI) indicate a decline in standard of living for the country since 2015. South Africa's ranking on the HDI is principally a consequence of life expectancy at birth (64.1 years in 2019).

2. SCIENCE, TECHNOLOGY AND INNOVATION TRENDS

Both local and international trends are an important component of STI indicators. Although COVID-19 is the leading issue of the period 2020–2021, its impact is poorly understood, and data is often rudimentary and unsuited; mostly not packaged in a way that can be used for policy analysis. However, where pertinent, reference is made to disruptions brought about by the pandemic.

2.1 Local trends in science, technology and innovation

Three broad issues are given consideration: the Fourth Industrial Revolution (4IR), the implementation of STI policy and progress towards attaining the United Nations' Sustainable Development Goals (SDGs).

2.1.1 Fourth Industrial Revolution-related emerging technologies

This sub-section provides a scientometric indication of the state of 4IR technologies and topics relevant to the 4IR in South Africa compared to the world. The following research topics are analysed: artificial intelligence, robotics, the Internet of Things, autonomous vehicles, additive manufacturing (3D printing), quantum computing and nanotechnology.

4IR-related scientific publications

Appendix A provides 4IR-related publications in areas such as the Internet of Things, additive manufacturing, quantum computing, nanotechnology, robotics, artificial intelligence and autonomous vehicles. South Africa's share of publications is highest in artificial intelligence, the Internet of Things and nanotechnology (Table 2.1).

Table 2.1: South African share of world publications, 2019

TECHNOLOGIES	SOUTH AFRICAN PUBLICATIONS	WORLD PUBLICATIONS	SOUTH AFRICA'S SHARE OF WORLD PUBLICATIONS
Internet of Things	81	12 303	**0.65%**
Additive manufacturing	31	7 551	**0.41%**
Quantum computing	9	1 777	**0.50%**
Nanotechnology	1 424	220 207	**0.64%**
Robotics	85	25 863	**0.32%**
Artificial intelligence	8	11 509	**0.72%**
Autonomous vehicles	54	9 269	**0.58%**

4IR-related patent applications

Europe, Japan and the USA, together, have accounted for about 80% of all 4IR European patent applications since 1978. The 4IR innovations started ten years later in South Korea and China, but since then, have been increasing at a faster rate than in other regions. South Africa, with 39 patents in the period 1990–2016, is the leading country in Africa. Egypt follows with three patents, Ethiopia with two patents and Mali with one patent.

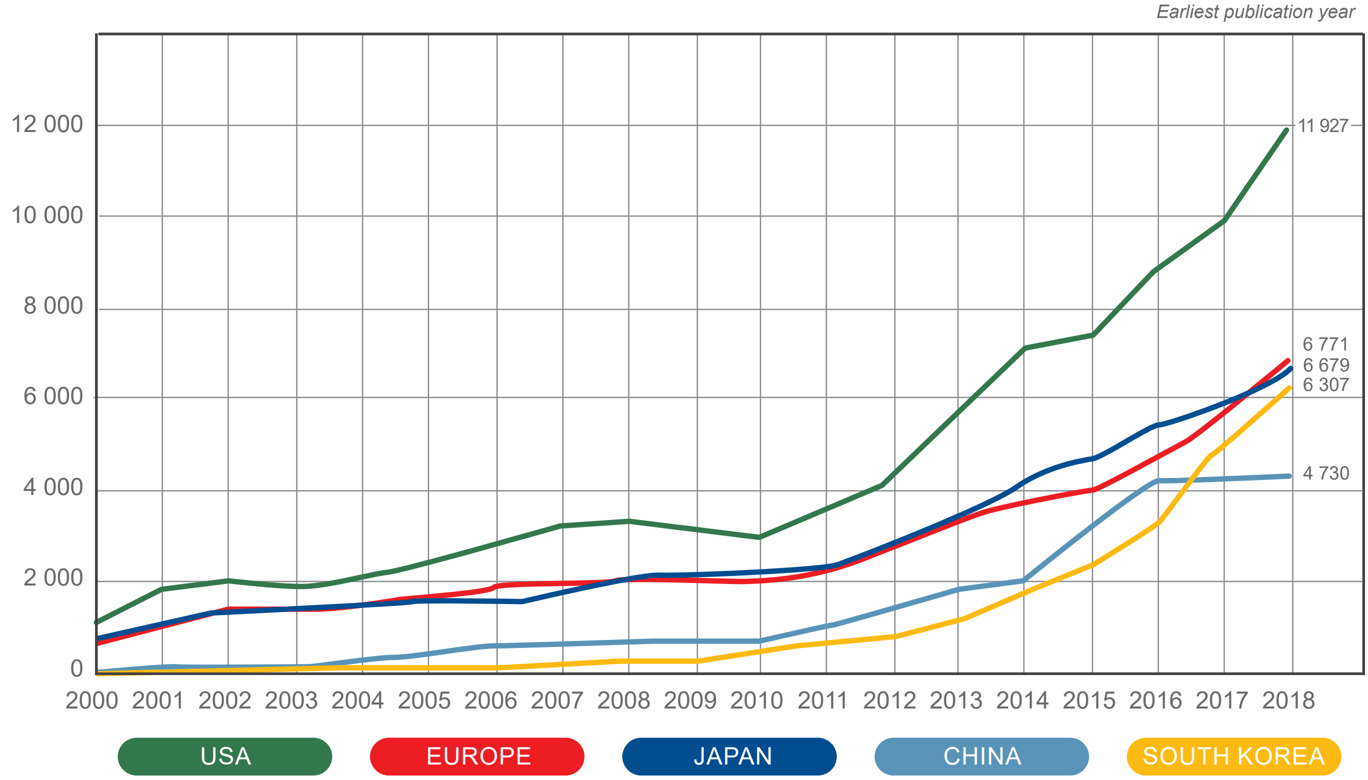


Figure 2.1: 4IR patents at the European Patents Office: leading countries

Source: European Patents Office, 2020

Table 2.2: The 4IR patent applications by BRICS countries at the European Patents Office (1990–2016)

COUNTRY	4IR PATENTS
China	1 687
India	326
Russia	109
South Africa	39
Brazil	29

Table 2.2 shows the number of patent applications of the Brazil, Russia, India, China and South Africa (BRICS) countries as registered at the EPO. China is at the top of the list with 1 687 patents. India follows with 326 inventions. South Africa is in fourth position with 39 patents, with Brazil at the bottom of the list with 29 patents.

Figure 2.2 shows the number of South African 4IR patents during the period 2001–2016. There is no clear trend.

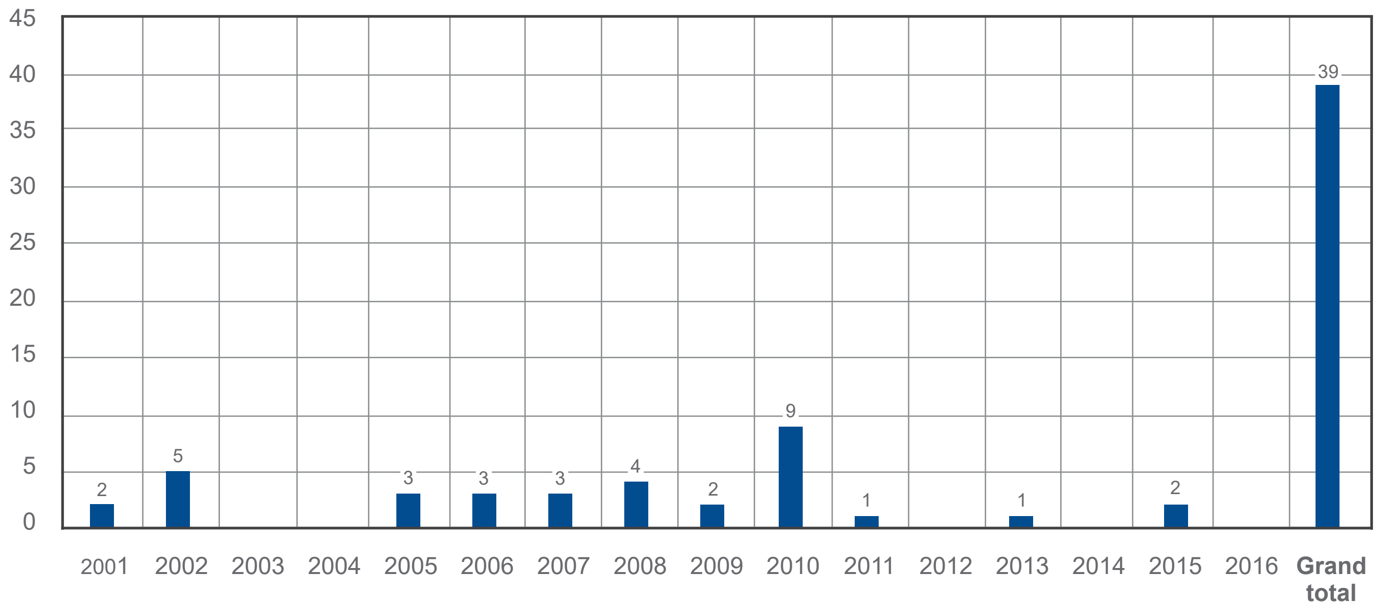


Figure 2.2: The European Patents Office's 4IR patents to South African inventors

2.1.2 Implementation of science, technology and innovation policy

The National Development Plan

Noting that 2021 marks the midpoint of the timespan set for the National Development Plan (NDP), this sub-section serves to commence with a review of the NDP's objectives that apply to the STI system. Table 2.3 offers an assessment of the targets that were set for 2030. On aggregate, the assessment suggests an STI system that has fallen short of expectations. A persistent shortcoming is the sub-optimal functioning of the education system.

Table 2.3: The 2030 targets of the National Development Plan

TARGET FOR 2030	STATUS	TREND
Gross fixed capital formation to 30%	• 19.1% (2011) • 17.9% (2019)	**Erratic; downward**
Improve Grade 9 TIMSS score from 264 to 420 by 2023	• 264 (2011) • 389 (2019)	**Up**
At least 80% of students should complete 12 years of schooling	• ±45% (2019)	**Steady**
Increase the number of students achieving 50% in Mathematical Literacy and Mathematics. *(Scores >40%)*	Mathematical Literacy • 61.4% (2011) • 54.5% (2019) Mathematics • 35.9% (2011) • 35.0% (2019)	**Down; steady**
Bachelor entry requirement met by 300 000 by 2024	• 186 058 (2019) • 4.3% compound annual growth rate (CAGR) ≥ 230 000 in 2024	**Upward**
Strengthen and expand the number of further education and training (FET) colleges to increase the participation rate to 25% (1 250 000)	Technical and vocational education and training (TVET) colleges consolidated to 50, with 200 associated campuses; enrolment 688 028 (2017)	**Slow rise**
Increase the graduation rate of FET colleges to 75%	Data unavailable	
Produce 30 000 artisans per year	• 21 551 (2017)	
Increase the participation rate at universities from 17% to 30% (from 950 000 to ±1.62 million)	• 22% (2018)	
Provide full funding assistance covering tuition, books, accommodation and living allowance to students from poor families.	Reduced university fees for needy students phased in from 2018	
Build new universities in the Northern Cape and Mpumalanga, and a medical school in Limpopo	New medical school under development in Nelson Mandela Bay	**Exceeded**
Increase proportion of black students graduating from universities. *(International African ±6%)*	• 76% of 160 000 (2011) • 84% of 227 188 (2019)	**Upward**
More than 5 000 doctoral graduates per year (1 420 in 2010)	• 3 344 (2018), of which 40% international	**Slow rise**
Increase percentage of PhD qualified staff in the higher education sector from 34% to over 75%	• 49% (2018)	**Slow rise**
Students from abroad who graduate from South African universities should qualify for a seven-year work permit	–	**Not implemented**
Spend more on R&D (2010 rands)	• R20.8 billion (2011) • R23.7 billion (2018)	**Flat**
Double number of graduate and postgraduate scientists (researchers)	Rise of 29% by 2018	**Slow rise**
Increase broadband speed to 2 Mps by 2020	Average speed 40 Mps	**Steeply up**
Reduction of high domestic cost of broadband internet connectivity	Cost of broadband internet ranked 101st out of 206 countries in 2020	**Flat**
Peak carbon-fuel use by 2025 *(Integrated Resource Plan (IRP) target)*	IRP projects no decrease out to 2035	**No**

Ten-Year Innovation Plan

The 2008–2018 Ten-Year Innovation Plan laid out a set of stretch targets for the innovation system. It is useful to revisit some of these (Table 2.4).

Table 2.4: Ten-Year Innovation Plan targets

TARGET FOR 2018	STATUS	TREND
Science, engineering and technology graduates are 35% of total	• 28.6% (2018)	Not attained
20 000 full-time equivalent researchers	• 24 618 (2018)	Exceeded
2.6 full-time equivalent researchers per 1 000 of workforce	• 1.8 (2018)	Not attained
GERD: GDP of 1.5%	• 0.76% (2019)	Not attained
1% share of world science publications	• 0.83% (2020)	Not attained
More than 50% of firms use technology to innovate	• 69.9% innovative (2014–2016)	Attained
250 USPTO awards	• 224 (2019)	Not attained

Source: Department of Science and Innovation 2008–2018 Ten-Year Innovation Plan

It is noted that GERD: gross domestic product (GDP), the sentinel indicator, was not attained. On the other hand, the number of full-time equivalent researchers rose beyond the target level. The count of full-time equivalent researchers includes doctoral and postdoctoral students, whose complement rose sharply across the period of comparison.

2.1.3 Sustainable Development Goals

The Africa SDG Index and Dashboards Report serves as the authoritative check on country progress toward attaining the SDGs.

> "The 2020 Africa SDG Index ranks 52 African countries based on 97 indicators across all 17 goals. The SDG Index score signifies a country's position between the worst (0) and best (100) outcomes. Tunisia tops this year's ranking with a score of 67.1, meaning that the country is 67% of the way towards achieving the SDGs, according to our methodology."

South Africa is ranked 9th, with an average score of 62.2, below Egypt at 6th, Botswana at 7th and Ghana at 8th. Table 2.5 summarises South Africa's progress toward attaining the 17 SDG goals.

Table 2.5: Progress toward attaining the SDGs, South Africa 2020

SDG	GOAL	TREND
1.	No poverty	Flat
2.	Zero hunger	Up
3.	Good health and wellbeing	Up
4.	Quality education	Up
5.	Gender equality	Up
6.	Clean water and sanitation	Up
7.	Affordable and clean energy	Flat
8.	Decent work and economic growth	Flat
9.	Industry, innovation and infrastructure	Up
10.	Reducing inequality	N/A
11.	Sustainable cities and communities	Flat
12.	Responsible consumption and production	N/A
13.	Climate action	Up
14.	Life below water	Flat
15.	Life on land	Down
16.	Peace, justice, and strong institutions	Flat
17.	Partnerships for the goals	Up

Source: Sustainable Development Solutions Network 2020

Box 1 provides disaggregated level snapshots of sub-indicators where progress (highlighted in green) is evident.

Box 1: SDG sub-indicators

	VALUE	YEAR	RATING	TREND
SDG 4 – QUALITY EDUCATION				
Net primary enrolment rate (%)	87.0	2017	Challenges remain	↑
Mean years of schooling	10.1	2017	Challenges remain	→
Literacy rate (percentage of population aged 15 to 24)	95.3	2017	SDG achievement	—
Gross intake ratio to the last grade of lower secondary education (%)	75.0	2016	Significant challenges remain	—
SDG 9 – INDUSTRY, INNOVATION AND INFRASTRUCTURE				
Infrastructure score (worst 0 to 100 best)	65.9	2017	Challenges remain	→
Logistics Performance Index: Quality of trade and transport-related infrastructure (worst 1 to 5 best)	3.2	2018	SDG achievement	↑
Expenditure on research and development (percentage of GDP)	0.8	2016	Significant challenges remain	↗
Scientific and technical journal articles (per 1 000 of the population)	0.2	2018	Significant challenges remain	→
Mobile broadband subscriptions (per 100 of the population)	77.5	2018	SDG achievement	↑
Population using the internet (percentage)	56.2	2017	Challenges remain	↑
SDG 12 – RESPONSIBLE CONSUMPTION AND PRODUCTION				
Municipal solid waste (kg per capita per day)	1.3	2011	Challenges remain	—
Electronic waster (kg per capita)	5.7	2016	Challenges remain	—
Natural resources value realisation score (worst 0 to 100 best)	49.9	2017	Significant challenges remain	—
Production-based SO_2 emissions (kg per capita)	43.1	2012	Challenges remain	—
SO_2 emissions embodied in imports (kg per capita)	2.9	2012	SDG achievement	—
SDG 13 – CLIMATE ACTION				
People affected by climate-related disasters (per 100 000 of population)	1 550.0	2019	Major challenges remain	—
Energy-related CO_2 emissions (tCO_2 per capita)	9.1	2017	Major challenges remain	↗
CO_2 emissions embodied in imports (tCo_2 per capita)	0.5	2015	Challenges remain	↑
CO_2 emissions embodied in fossil fuel exports (kg per capita)	1 690.1	2018	Challenges remain	—
SDG 14 – LIFE BELOW WATER				
Ocean Health Index: Clean water score (worst 0 to 100 best)	55.6	2019	Significant challenges remain	→
Mean area that is protected in marine sites important to biodiversity (%)	51.9	2018	SDG achievement	↑
Fish caught from overexploited or collapsed stocks (% of total catch)	33.6	2014	Challenges remain	↓
Fish caught by trawling (%)	26.6	2014	Challenges remain	↓
Marine biodiversity threats embodied in imports (per million population)	0.1	2018	SDG achievement	—
SDG 15 – LIFE ON LAND				
Mean area that is protected in terrestrial sites important to biodiversity (%)	30.7	2018	Challenges remain	→
Permanent deforestation (% of forest area, five-year average)	0.1	2018	Challenges remain	—
Red List Index or species survival (worst 0 to 1 best)	0.8	2019	Significant challenges remain	↓
Terrestrial and freshwater biodiversity threats embodied in imports (per million population)	0.8	2018	SDG achievement	—

SDG achievement | Challenges remain | Significant challenges remain | Major challenges remain

↑ On track | ↗ Moderately increasing | → Stagnating | ↓ Decreasing

Source: Sustainable Development Solutions Network 2020

No data was available for SDG 10 (Reduce inequality) and SDG 12 (Responsible consumption and production). There was a decline in SDG 15 (Life on land). It may be noted that no SDG is "on track" for attainment.

2.2 Global trends in science, technology and innovation

Continuous monitoring of global STI trends is important for the country to remain competitive relative to other peer countries. This section analyses the key global STI trends, such as R&D expenditure, scientific publications, technological inventions, innovation and competitiveness.

2.2.1 R&D expenditure

The R&D expenditure as a percentage of GDP from various economies is shown in Table 2.6. In 2017, the world R&D intensity experienced a slight increase from 1.69% in 2016 to 1.72%. This increase was driven by the high-income and upper middle-income economies, as both the lower and low-income countries experienced a decline. Among the BRICS group of countries, China has the largest R&D intensity (2.19% in 2018) and India has the smallest (0.65%). Countries such as Israel and South Korea have the largest R&D intensity globally, with South Korea reaching 4.81% in 2018. In Africa, the northern countries, such as Egypt and Tunisia, are catching up with South Africa in terms of R&D intensity. Although the country's R&D intensity in 2009 was nearly double that of Egypt, in 2018, Egypt had an R&D intensity of 0.72% vis-à-vis 0.75% for South Africa.

Table 2.6: Global trends in gross expenditure on R&D as a percentage of GDP

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
WORLD	**1.65**	**1.62**	**1.64**	**1.65**	**1.67**	**1.68**	**1.69**	**1.69**	**1.72**	**–**
Low-income countries	**0.25**	**0.27**	**0.28**	**0.29**	**0.31**	**0.30**	**0.30**	**0.30**	**0.29**	**–**
Tajikistan	0.09	0.09	0.12	0.11	0.12	0.12	0.11	0.11	0.12	0.10
Lower middle-income countries	**0.49**	**0.48**	**0.49**	**0.47**	**0.45**	**0.44**	**0.43**	**0.44**	**0.43**	**–**
Egypt	0.43	0.43	0.53	0.51	0.64	0.64	0.72	0.71	0.68	0.72
India	0.83	0.79	0.76	0.74	0.71	0.70	0.69	0.67	0.67	0.65
Tunisia	0.71	0.69	0.71	0.68	0.67	0.65	0.63	0.60	–	0.60
Upper middle-income countries	**1.10**	**1.13**	**1.16**	**1.24**	**1.31**	**1.36**	**1.41**	**1.45**	**1.48**	**–**
Brazil	1.12	1.16	1.14	1.13	1.20	1.27	1.34	1.26	1.26	–
China	1.66	1.71	1.78	1.91	2.00	2.03	2.07	2.12	2.15	2.19
Russia	1.25	1.13	1.01	1.03	1.03	1.07	1.10	1.10	1.11	0.99
South Africa	0.84	0.74	0.73	0.73	0.72	0.77	0.80	0.82	0.83	0.75
High-income countries	**2.33**	**2.30**	**2.34**	**2.33**	**2.36**	**2.38**	**2.37**	**2.37**	**2.42**	**–**
Singapore	2.13	1.93	2.07	1.92	1.92	2.08	2.18	2.08	1.94	–
South Korea	3.29	3.47	3.74	4.03	4.15	4.29	4.22	4.23	4.55	4.81
United States	2.81	2.74	2.77	2.68	2.71	2.72	2.72	2.76	2.82	2.84

Source: UNESCO Institute for Statistics

2.2.2 World talent ranking

Over the last five years, South Africa has been slipping down on the International Institute for Management Development (IMD)'s world talent ranking (Figure 2.3). It ranked 43rd in 2016, and in 2020 its ranking was 52nd out of 63 countries. An area of strength for South Africa is its appeal to the international talent pool (40th in 2020). An example is an increasing proportion of South African PhD students that came mainly from other African countries. The indicators in which South Africa is performing well on this component of the world talent ranking are cost-of-living index (second in 2020) and effective personal income tax rate (third).

In terms of investment and development of the local talent pool, the country is performing well on public expenditure on education as a percentage of GDP (first in 2020) and female labour force as a percentage of total labour force (35th). In the area of talent readiness, South Africa is dragged low by indicators such as ability of primary and secondary education to meet the needs of a competitive economy (60th), percentage of graduates in information and communication technology (ICT), engineering, maths and natural sciences (55th), skilled labour (55th) and international experience of senior managers (55th).

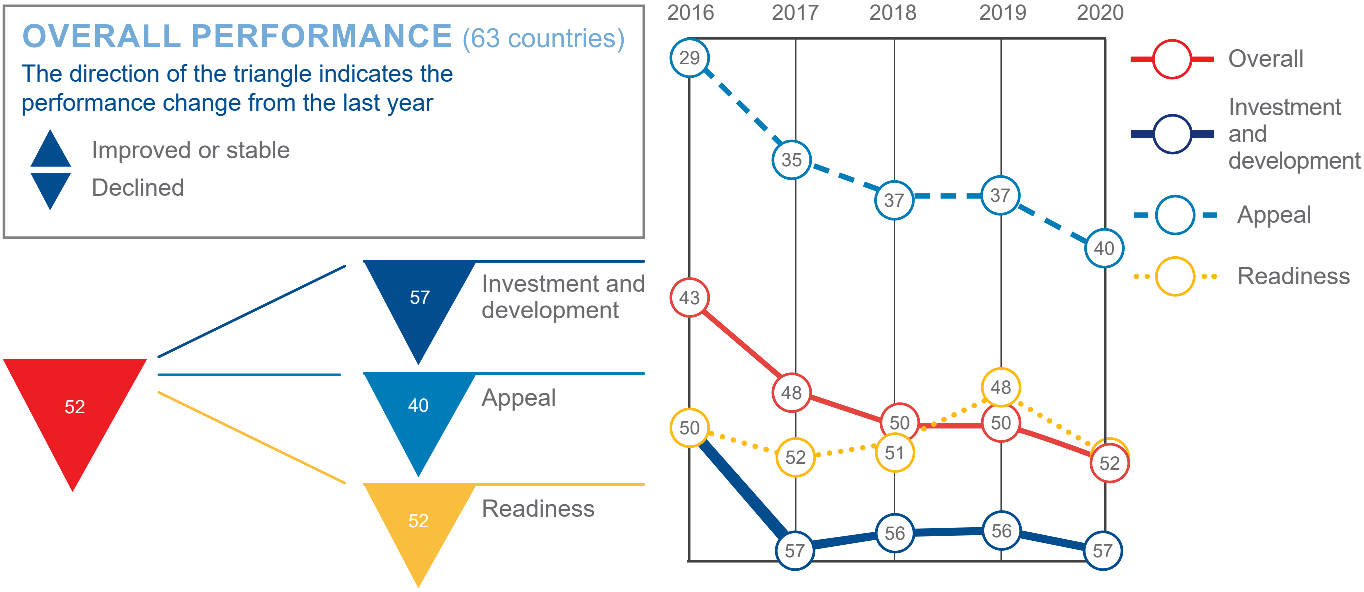


Figure 2.3: South Africa's performance on the world talent ranking
Source: Institute for Management Development World Talent Ranking 2020

The benchmarking of South Africa with other countries (Table 2.7) shows that, among the BRICS group of countries, it is performing well above Brazil (59th in 2020), India (62nd) and Russia (54th), but lower than China (40th).

Table 2.7: Benchmarking of the Institute for Management Development's World Talent Ranking 2020

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	MALAYSIA	RUSSIA	SINGAPORE	SOUTH KOREA	UNITED KINGDOM	USA
Overall ranking	52	59	40	62	25	54	9	31	23	15
Investment and development *(home-grown talent)*	57	56	42	63	34	47	21	28	38	17
Appeal *(to overseas talent)*	40	45	52	55	29	62	22	36	20	2
Readiness *(availability of skills and competencies within talent pool)*	52	63	26	25	18	47	1	29	17	27

Source: Institute for Management Development World Talent Ranking 2020

2.2.3 Scientific publications

The number of publications per million of the population is shown in Table 2.8 for different economic groups of countries and select countries. Despite South Korea and the USA having a large R&D intensity in comparison to Singapore, the latter has better efficiency in knowledge generation.

South Africa also has a higher knowledge-generation efficiency (publications relative to population) in comparison to the average of the upper middle-income countries and other members of the BRICS group of countries (except Russia). Among South Africa's neighbouring countries, Botswana produces comparably more scientific publications per million inhabitants (333 in 2019).

Table 2.8: Global trends in scientific publications per million inhabitants

	2011	2012	2013	2014	2015	2016	2017	2018	2019
WORLD	**326**	**336**	**346**	**356**	**401**	**415**	**423**	**422**	**437**
Low income	**10**	**10**	**11**	**12**	**16**	**17**	**20**	**20**	**23**
Mozambique	10	8	8	9	14	16	19	18	21
Lower middle income	**43**	**47**	**52**	**58**	**77**	**84**	**89**	**94**	**99**
Egypt	102	114	124	138	181	200	204	225	250
Eswatini	12	6	9	7	14	17	10	33	84
India	49	54	62	71	93	100	101	104	106
Nigeria	19	18	18	21	30	33	38	41	46
Tunisia	373	401	469	520	656	705	765	702	700
Upper middle income	**186**	**205**	**220**	**239**	**285**	**313**	**338**	**360**	**396**
Botswana	150	145	144	192	204	277	284	305	333
Brazil	237	253	266	276	348	362	383	399	423
China	272	223	244	267	297	328	352	380	439
Russia	252	253	267	307	437	513	570	622	649
South Africa	248	278	285	309	390	424	445	451	476
High income	**1 688**	**1 758**	**1 824**	**1 904**	**2 103**	**2 184**	**2 218**	**2 233**	**2 318**
Singapore	2 765	3 070	3 305	3 497	3 913	4 113	4 172	4 200	4 277
South Korea	2 410	2 686	2 726	2 924	3 261	3 356	3 367	3 432	3 614
United States	1 981	2 051	2 089	2 156	2 318	2 395	2 438	2 441	2 493

Source: Computed from the Web of Science "Core Collection"

2.2.4 Intellectual property protection

A patenting pattern for some of the countries is different from patterns observed for scientific publications. Most countries are more skewed towards knowledge generation in comparison to knowledge application (patents as proxy for inventions). The list includes Botswana, Egypt, Singapore, South Africa and Tunisia (Table 2.9).

Table 2.9: Global trends in patent applications per million inhabitants

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
WORLD	**289**	**308**	**333**	**357**	**368**	**392**	**420**	**421**	**438**	**420**
Low income	**18**	**18**	**18**	**3**	**4**	**3**	**3**	**3**	**3**	**3**
Mozambique	1	0.3	1	1	1	1	1	1	1	1
Lower middle income	**24**	**25**	**25**	**25**	**24**	**25**	**24**	**25**	**26**	**28**
Egypt	8	9	9	9	10	9	11	12	12	12
Eswatini	70	7	60	21	32	11	15	68	84	28
India	1	13	14	16	17	2	20	21	22	25
Nigeria	0.3	0.5	0.3	0.4	0.1	0.3	1	1	1	0.1
Tunisia	12	14	18	20	16	19	24	16	17	1
Upper middle income	**199**	**250**	**299**	**360**	**394**	**457**	**536**	**545**	**596**	**542**
Botswana	1	2	18	10	7	3	1	3	0,4	1
Brazil	29	32	33	34	33	3	35	36	33	35
China	230	324	416	541	614	737	912	942	1 048	950
Russia	230	220	240	237	198	235	221	192	212	206
South Africa	39	34	32	41	42	38	36	38	32	26
High income	**1 184**	**1 192**	**1 236**	**1 256**	**1 261**	**1 271**	**1 272**	**1 269**	**1 265**	**1 289**
Singapore	833	882	919	1 013	1 084	1 117	1 201	1 239	1 315	1 289
South Korea	7 313	7 648	8 261	9 013	9 248	9 505	9 284	8 954	9 124	9 723
United States	140	1 415	1 509	1 586	160	1 655	1 617	1 617	1 577	1 588

Source: Computed from the World Intellectual Property Office's IP Statistics Data Centre

South Korea and China are more inclined towards technology development in comparison to knowledge creation, as shown by the huge number of patent applications per million of the population for these countries in comparison to scientific publications.

Eswatini's innovation system is also geared more towards technology development in comparison to scientific publications, although its patenting activity is not sustained as there was a huge decline from 2018 to 2019. Despite this huge decline for Eswatini's patents in 2019, its patents per million of the population in 2019 (28) were still slightly more than those of South Africa (26 in 2019).

2.2.5 The Global Innovation Index

South Africa was ranked 60th on the 2020 Global Innovation Index (GII), an improvement from 63rd in 2019 (see Table 2.10). The Innovation Inputs pillar remains a strong area for South Africa.

Table 2.10: The 2020 Global Innovation Index rankings

	OVERALL GII	INNOVATION INPUTS	INNOVATION OUTPUTS
	RANKING OUT OF 131 COUNTRIES		
WORLD	**55**	**59**	**59**
Africa	**104**	**102**	**102**
South Africa	60	49	68
Botswana	89	84	104
Egypt	96	104	82
Mozambique	124	122	125
Namibia	104	101	105
Nigeria	117	115	105
Tunisia	65	77	59
Zimbabwe	120	123	108
BRICS	**41**	**42**	**43**
Brazil	62	59	64
China	14	26	6
India	48	57	45
Russia	47	42	58
Upper middle income	**66**	**69**	**61**
Malaysia	33	34	36
Other select countries			
Singapore	8	1	15
South Korea	10	9	10
United Kingdom	4	6	3
United States	3	4	5

Source: Computed by NACI from the 2020 Global Innovation Index report

Among the BRICS group of countries, China is the most innovative (14th), especially on innovation outputs (6th). South Africa's ranking on innovation inputs is above that of Brazil (59th) and India (57th), although it is the lowest on innovation outputs within the BRICS group of countries. Among the most developed economies included in this benchmark, the USA and the United Kingdom are performing very well on the GII, although Singapore is the overall leader on innovation inputs.

As Table 2.11 shows, the main drivers of the USA's performance are market sophistication (2nd), knowledge and technology (3rd) and business sophistication (5th). Market sophistication is also an area of strength for South Africa (15th). This component includes areas such as ability to secure credit, investment opportunities, as well as trade, competition and market scale. Tunisia outperforms South Africa on areas such as human capital and research, infrastructure, knowledge and technology, as well as creative outputs. Botswana is also above South Africa on the human capital and research component. The indicators in this component are in the areas of schooling, tertiary education and R&D. The ranking for South Africa on this component (70th) is equal to the average of the upper middle-income countries, but is very low in comparison to the average for the BRICS member countries (43rd).

Table 2.11: Equivalent ranking of GII pillars by income group

	INNOVATION INPUTS					INNOVATION OUTPUTS	
	INSTITUTIONS	HUMAN CAPITAL AND RESEARCH	INFRA-STRUCTURE	MARKET SOPHISTI-CATION	BUSINESS SOPHISTI-CATION	KNOWLEDGE AND TECHNOLOGY OUTPUTS	CREATIVE OUTPUTS
WORLD	**58**	**59**	**62**	**62**	**49**	**54**	**57**
Africa	**93**	**103**	**106**	**106**	**102**	**101**	**104**
South Africa	55	70	77	15	50	61	70
Botswana	60	53	103	96	99	89	111
Egypt	115	90	100	106	103	65	101
Mozambique	127	108	83	125	124	122	122
Namibia	69	114	112	103	111	127	79
Nigeria	110	121	124	102	75	120	110
Tunisia	75	38	74	112	110	52	63
Zimbabwe	128	93	131	84	108	101	112
BRICS	**66**	**43**	**60**	**34**	**35**	**37**	**57**
Brazil	83	49	61	91	35	56	77
China	62	21	36	19	15	7	12
India	61	61	75	31	55	27	64
Russia	71	30	60	55	42	50	60
Upper middle income	**71**	**70**	**71**	**65**	**62**	**64**	**61**
Malaysia	40	29	48	20	31	38	35
Other select countries							
Singapore	1	8	13	4	6	14	18
South Korea	29	1	14	11	7	11	14
UK	16	10	6	5	19	9	5
USA	9	12	24	2	5	3	11

Source: Computed by NACI from the Global Innovation Index data

2.2.6 World competitiveness

South Africa's ranking on the IMD's World Competitiveness Ranking continues to deteriorate, falling from 56th in 2019 to 59th in 2020 (see Table 2.12).

Table 2.12: Benchmarking on World Competitiveness Ranking

	OVERALL PERFORMANCE		ECONOMIC PERFORMANCE		GOVERNMENT EFFICIENCY		BUSINESS EFFICIENCY		INFRASTRUCTURE	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
	RANKING OUT OF 63 COUNTRIES									
South Africa	56	59	59	61	50	54	44	56	60	61
Brazil	59	56	57	56	62	61	57	47	54	53
China	14	20	2	7	35	37	15	18	16	22
India	43	43	24	37	46	50	30	32	55	49
Malaysia	22	27	11	9	24	30	18	29	28	31
Phillipines	46	45	38	44	41	42	32	33	59	59
Russia	45	50	31	47	47	48	53	58	37	42
Singapore	1	1	5	3	3	5	5	6	6	7
South Korea	28	23	27	27	31	28	34	28	20	16
United Kingdom	23	19	22	24	19	18	31	20	14	12
United States	3	10	1	2	23	26	11	14	1	5

Source: Institute for Management Development's World Competitiveness Ranking 2020

This ranking places the country as the worst among the BRICS group of countries and very low in relation to comparable economies such as Malaysia and the Phillipines. Deteriorating business efficiency is the main driver of this downward trend. The lowest ranked indicators on business efficiency are productivity and efficiency (59th), management practices (57th) and attitudes and values (57th). Infrastructure and economic performance rank the lowest in terms of pillars of competitiveness for South Africa (both 61st in 2020).

As shown in Figure 2.4, the infrastructure includes indicators such as basic infrastructure (61st), technological infrastructure (60th), scientific infrastructure (43rd), health and environment (60th) and education (59th). A low rate of inflation ranks high (5th) as part of economic performance. Similarly, an excellent tax policy is ranked 11th for South Africa as part of government efficiency.

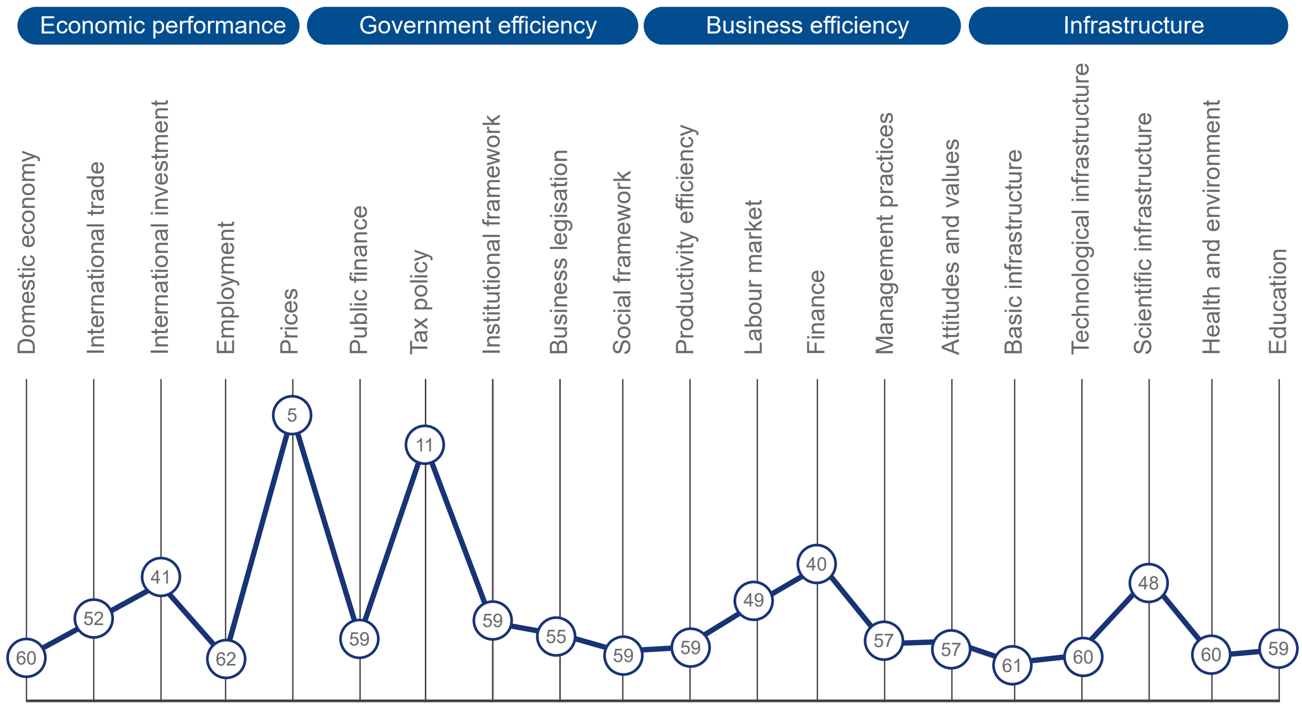


Figure 2.4: South African competitiveness landscape, 2020
Source: Institute for Management Development's World Competitiveness Ranking 2020

3. SCIENCE, TECHNOLOGY AND INNOVATION FRAMEWORK CONDITIONS

Enabling framework conditions for STI are necessary to support innovation value chain activities, including research, technology development, new product and process development, and commercialisation. Framework conditions must address the provision and retention of STI human capital, a well-functioning research system and a positive environment for innovation.

3.1 Science, technology and innovation human capital

Talent is the *sine qua non* of all innovation systems. Without skilled and committed personnel, the innovation system will not perform to expectation. Furthermore, if the talent stock is constrained in size, the innovation system will not grow in real terms. Skilled personnel are at the very heart of the innovation system.

3.1.1 Human resources in research and development

The data in Appendix B serves to illustrate aspects of R&D personnel for the period 2001/02 to 2018/19. Column A records the total number of research staff, being those employed as permanent and pensionable, or on contract for six months or longer. Column B is the researcher headcount for the universities and is comparable with the value recorded on the Higher Education Management Information System (HEMIS) as research and instruction staff.

According to the guidelines of the Frascati Manual[1], doctoral and postdoctoral students (Column C) are counted as part of the total researcher complement (Column D). Columns E to G are self-explanatory. Columns H and I present simple ratios. The trends evident in the data over the 18-year period are as follows:

- The researcher (payroll) headcount across all sectors (business, government, science councils, not-for-profit organisations (NPOs) and universities) increased by 73.2%.
- The headcount of university researchers and technicians doubled. University student enrolment (Column F) also doubled.
- There was a fourfold increase in the number of doctoral and postdoctoral students, with a corresponding twofold increase in total researchers.
- The ratio of university researchers to doctoral and postdoctoral students declined from 2:1 to unity, implying an increased burden of supervision.
- The ratio of total researchers to technicians remained steady at around 5:1.

The data of Table 3.1 presents the full-time equivalent availability of researchers by sector, over time. The higher education total excludes postgraduate students. The ratio of GERD per full-time equivalent (FTE) researcher is presented in current rands.

1 OECD, 2015. Frascati Manual: Guidelines for collecting and reporting data on research and experimental development. Available at: http://www.oecd.org/sti/frascati-manual-2015-9789264239012-en.htm.

Table 3.1: Researchers per sector and R&D expenditure per researcher

	BUSINESS	NPO	GOVERNMENT	SCIENCE COUNCILS	HIGHER EDUCATION	TOTAL	GERD (MILLION R)	GERD/ RESEARCHER
2011/12	4 451,90	190,80	1 009,80	1 634,90	4 355,30	11 642,70	22 209	1 907 547
2012/13	4 555,90	294,50	1 091,40	1 697,10	4 700,60	12 339,50	23 871	1 934 519
2013/14	4 530,10	338,40	93,70	1 781,20	5 000,50	11 743,90	25 661	2 185 049
2014/15	4 636,20	396,00	970,00	1 765,40	5 097,70	12 865,30	29 345	2 280 942
2015/16	4 626,80	384,80	953,90	1 827,20	4 701,90	12 494,60	32 337	2 588 078
2016/17	4 777,30	340,50	969,10	1 940,50	5 220,40	13 247,80	35 693	2 694 259
2017/18	5 481,70	346,10	899,10	1 792,10	6 040,60	14 559,60	38 725	2 659 757
2018/19	4 535,10	367,30	920,80	1 697,00	6 007,20	13 527,40	36 784	2 719 222

- GERD (current rands) per FTE payroll researcher has risen steadily at a CAGR of 7%, in excess of the average inflation of 4.7% over the same period. This implies a real rise in GERD, i.e. a proxy for labour costs.
- The core R&D labour force (researchers) has increased by 35%, but its cost has increased by 270%.

The above evidence is sufficient to argue that the research and innovation system is constrained in size, in that the core headcount of researchers is growing slowly, even as expenditure has grown steadily.

It may be noted that, up to 2019, some 40% of doctoral graduates were international students, and 60% of postdoctoral students hailed from abroad. It is estimated that 40% of doctoral graduates and the majority of postdoctoral students enjoy the support of the NRF[2]. A tracer study has found that close to two-thirds of foreign doctoral students for the period 2012–2016, emerging from the five research universities, returned to their home countries upon graduation. A small proportion of these graduates (<10%) remained in South Africa.

The implication is that the growth of the innovation system is strongly dependent on the presence of international students. The complement of international students is a factor accounted for in the Times Higher Education World Ranking calculation.

3.1.2 Engineers, technologists and technicians practising in South Africa

In 2019/20, South Africa had 19 523 professional engineers registered with the Engineering Council of South Africa (ECSA). This translates to 33 professional engineers per 100 000 of the population. More than 94% of registered professional engineers are male. A similar gender imbalance is observed with regard to engineering technologists, professional certified engineers and professional engineering technicians. About 15 966 of registered engineers are white (82%) followed by African (2 176 or 11%), Indian (1 149 or 6%) and coloured (232 or 1%).

2 Kahn and Oghenetega, 2021. Origins and destinations known: A tracer study of international African doctoral graduates from South Africa's universities. *Industry and Higher Education*.

Table 3.2: Registered engineers, technologists and technicians, 2020

		PROFESSIONAL ENGINEERS	PROFESSIONAL ENGINEERING TECHNOLOGISTS	PROFESSIONAL CERTIFICATED ENGINEERS	PROFESSIONAL ENGINEERING TECHNICIANS
Gender	Female	1 138	489	6	767
	Male	18 385	5 923	1 057	3 081
Race	African	2 176	2 011	76	2 521
	Coloured	232	248	12	188
	Indian	1 149	493	35	189
	White	15 966	3 660	940	950
Total		**19 523**	**6 412**	**1 063**	**2 848**

Source: Engineering Council of South Africa

As Figure 3.1 shows, there is a huge correlation between number of engineers and the economy among the Southern African Development Community (SADC) member countries. Seychelles had the highest number of engineers per 100 000 of the population and also the highest GDP per capita. On the lower end, Malawi and the Democratic Republic of Congo had the lowest GDP per capita, as well as the lowest number of engineers per 100 000 of the population.

This correlation is not true for countries such as Angola and Namibia. Angola, as a resource-based country, is not very reliant on engineering capability to grow the economy. Similar to South Africa, Namibia is a services-based economy with services contributing 59% to its economy in 2019.

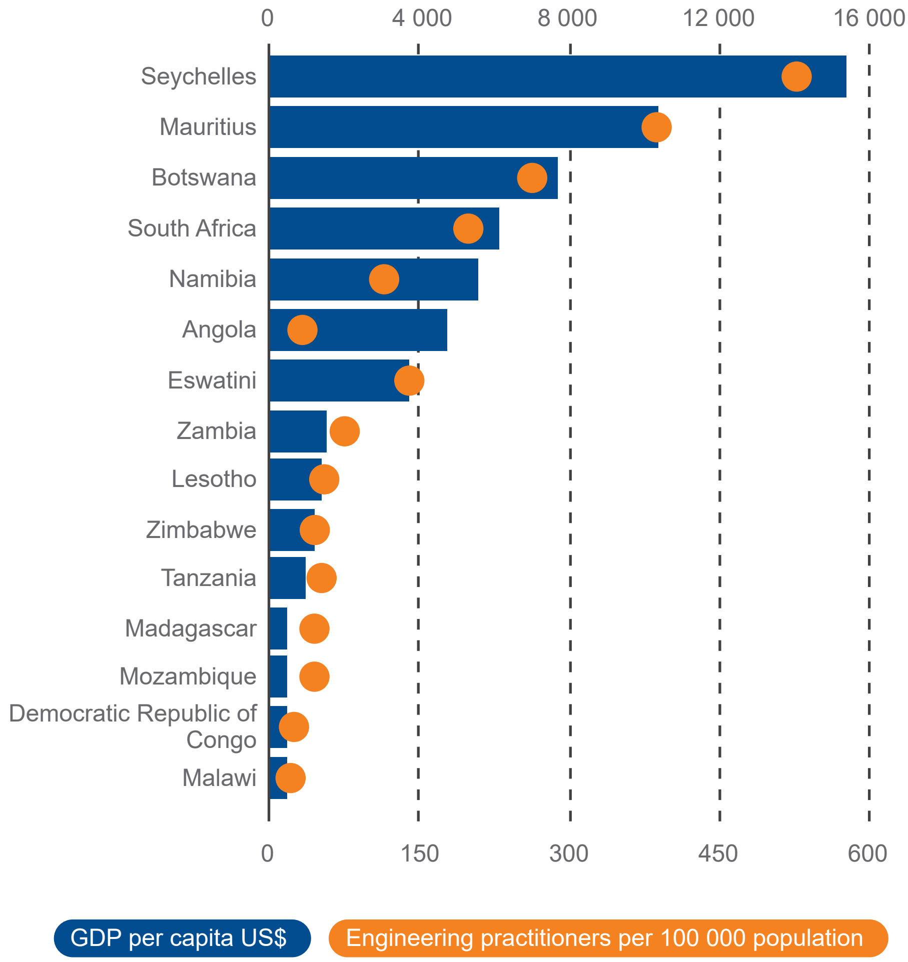


Figure 3.1: GDP per capita vs engineers per 100 000 of the population, 2016
Source: UNESCO Engineering for Sustainable Development, 2021

3.1.3 University SET enrolments and graduations

Most of the human resources required by the research and innovation system are supplied by public universities. with other sources such as private higher education (HE) institutions and the TVET system playing a far smaller role. The proportion of both enrolments and graduates in SET is steady at around 30% of the total (see tables 3.3 and 3.4). The Ten-Year Innovation Plan set a target of 35% for SET graduates by 2018.

Table 3.3: Enrolments by field of study

	2013	2014	2015	2016	2017	2018	2019
Business and commerce	279 954	272 408	273 828	264 934	278 930	283 193	265 974
Education	172 991	166 099	170 550	176 986	195 113	214 151	211 274
Humanities	247 131	243 426	245 899	238 535	252 826	267 553	274 377
SET	283 622	287 221	294 935	295 383	310 115	320 670	323 286
SET percentage	28.8	29.6	29.9	30.3	29.9	29.5	30.1

Source: Department of Higher Education and Training HEMIS

Table 3.4: Graduates by field of study

	2013	2014	2015	2016	2017	2018	2019
Business and commerce	48 714	50 054	53 232	55 558	57 007	59 749	58 668
Education	37 664	36 761	36 164	41 938	44 291	50 479	47 492
Humanities	39 745	41 808	42 223	44 966	46 657	50 252	51 095
SET	52 570	54 950	57 250	58 341	60 985	64 430	64 683
SET percentage	29.4	29.9	30.3	29.1	29.2	28.6	29.1

Source: Department of Higher Education and Training HEMIS

The 2014–2019 snapshots offered as tables 3.5 and 3.6 speak to shifts in the pattern of enrolments and graduations for African, coloured, Indian and white students. While the number of African students is now in excess of other groups combined, the Indian and white groups show the highest proportion of enrolments and graduates in SET.

Table 3.5: Enrolments by group and field of study

	2014				2019			
	AFRICAN	COLOURED	INDIAN	WHITE	AFRICAN	COLOURED	INDIAN	WHITE
Business and commerce	191 680	16 607	19 264	43 403	207 528	13 600	13 393	29 203
Education	126 883	8 972	6 695	22 463	171 441	13 276	5 837	20 055
Humanities	170 159	18 676	9 949	41 793	217 714	18 893	7 885	28 721
SET	191 627	16 461	17 703	58 611	231 112	16 594	17 215	48 776
Total	**680 349**	**60 716**	**53 611**	**166 173**	**827 795**	**62 363**	**44 330**	**126 755**
SET percentage	28.2	27.1	33.0	35.2	27.9	26.6	38.8	38.5

Source: Department of Higher Education and Training HEMIS

The number of African students enrolled in SET is rising sharply. The ratio of African students to white students has doubled in the last decade and, all things being equal, would double again by 2030. That would give rise to a situation of representation according to demographic distribution.

Table 3.6: Graduates by group and field of study

	2014				2019			
	AFRICAN	COLOURED	INDIAN	WHITE	AFRICAN	COLOURED	INDIAN	WHITE
Business and commerce	32 696	3 160	3 750	10 448	42 546	3 149	3 326	8 991
Education	27 798	2 179	1 328	5 456	37 746	2 893	1 421	5 203
Humanities	27 169	3 022	1 746	9 871	37 383	3 789	1 744	7 511
SET	34 483	3 267	3 432	13 768	43 566	3 740	4 008	12 553
Total	**122 146**	**11 628**	**10 256**	**39 543**	**161 241**	**13 571**	**10 499**	**34 258**
SET percentage	**28.2**	**28.1**	**33.5**	**34.8**	**27.0**	**27.6**	**38.2**	**36.6**

Source: Department of Higher Education and Training HEMIS

Table 3.7 provides a ten-year overview of enrolments for master's and doctoral studies. Two features stand out. First is a slow rise in the proportion of those studying in SET fields. The second is that doctoral enrolments have risen by a factor of 2.4 compared with master's enrolments that have risen 0.5-fold.

Table 3.7: Enrolment by qualification and field

	2009			2014			2019		
	TOTAL	SET	SET PERCENTAGE	TOTAL	SET	SET PERCENTAGE	TOTAL	SET	SET PERCENTAGE
Master's	43 723	18 926	43.3	55 675	24 455	43.9	62 157	29 766	47.9
Doctoral	10 529	5 092	48.4	17 943	8 755	48.8	24 386	12 302	50.4
Total	**54 252**	**24 018**	**44.3**	**73 618**	**33 210**	**45.1**	**86 543**	**42 068**	**48.6**

Source: Department of Higher Education and Training HEMIS

Table 3.8 provides the ten-year overview of graduations in master's and doctoral degrees, including the broad SET field. Two features stand out. First is a decline in the proportion of master's graduates in SET fields compared with a small rise in doctoral graduates. The second is that doctoral enrolments have risen nearly three-fold to 1 841, a quantum that is still short of the 3 000 that was targeted in the Ten-Year Innovation Plan.

Table 3.8: Graduation by qualification and field

	2009			2014			2019		
	TOTAL	SET	SET PERCENTAGE	TOTAL	SET	SET PERCENTAGE	TOTAL	SET	SET PERCENTAGE
Master's	8 112	4 832	59.6	11 627	5 038	43.3	13 519	6 341	46.9
Doctoral	1 380	677	49.1	2 258	1 130	50.0	3 445	1 841	53.4
Total	**9 492**	**5 509**	**58.0**	**13 885**	**6 168**	**44.4**	**16 964**	**8 182**	**48.2**

Source: Department of Higher Education and Training HEMIS

What must be recognised is that in the order of 35% of the 1 841 doctoral degrees were awarded to international students, who are subject to work permit regulations, so that the number of SET doctoral graduates immediately available to the research market would be in the order of 1 200, well below the target of 3 000.

3.1.4 Trends in Mathematics and Science Study

It can be deduced from Table 3.9 that the country's average scores in the 2019 TIMSS are below the minimum benchmark level of 400 for both Mathematics and Science in Grade 5 and Grade 9. The Medium-term Strategic Framework (MTSF) targets an average TIMSS score of 426 by 2023 for Grade 5 learners, from a baseline of 376 in 2015. For Grade 9, the target is to increase the average score in Mathematics and Science to 420 in 2023 from the 2015 baseline of 372 and 358, respectively. There is an incremental increase in Grade 9 TIMSS scores, although the rate of increase is low to achieve the MTSF target. Grade 9 Mathematics remains the same (within one standard deviation) from 2015 to 2019.

A key concern for the NSI is the very low percentage of learners who achieve the high and advanced international benchmark on TIMSS.

Table 3.9: Summary of South African performance on TIMSS

INTERNATIONAL BENCHMARK	GRADE 5			GRADE 9					
	MATHEMATICS		SCIENCE	MATHEMATICS			SCIENCE		
	2015	2019	2019	2011	2015	2019	2011	2015	2019
Advanced (>625)	1%	1%	2%	1%	1%	1%	1%	1%	1%
High (550–625)	4%	4%	4%	2%	3%	2%	3%	4%	4%
Intermediate (475–550)	12%	11%	8%	6%	10%	10%	7%	9%	10%
Low (400–475)	22%	21%	14%	18%	21%	28%	14%	18%	21%
Not achieved (<400)	61%	63%	72%	73%	66%	59%	75%	68%	64%
Average South African scores	376	374	324	352	372	389	332	358	370

Source: International Association for the Evaluation of Educational Achievement's TIMSS 2019

Table 3.10 shows that the main challenge is with regard to learners who attend no-fee-paying schools. In Grade 9, for both Mathematics and Science, a proportion of learners achieving the high and advanced international benchmark is zero vis-à-vis a much better performance for learners attending fee-paying schools. For Grade 5 Science, about 86% of learners from no-fee-paying schools could not achieve a minimum 400 benchmark score compared to only 40% for learners who attend fee-paying schools. No-fee-paying schools are mainly in quintiles 1 to 3, whereas fee-paying schools fall mainly under quintiles 4 and 5.

Table 3.10: Summary of South African TIMSS performance by fee status, 2019

INTERNATIONAL BENCHMARK	GRADE 5				GRADE 9			
	MATHEMATICS		SCIENCE		MATHEMATICS		SCIENCE	
	FEE-PAYING	NO-FEE-PAYING	FEE-PAYING	NO-FEE-PAYING	FEE-PAYING	NO-FEE-PAYING	FEE-PAYING	NO-FEE-PAYING
Advanced (>625)	3%	0%	5%	0%	2%	0%	4%	0%
High (550–625)	12%	1%	13%	1%	8%	0%	11%	0%
Intermediate (475–550)	24%	5%	20%	3%	22%	4%	22%	5%
Low (400–475)	28%	18%	22%	10%	36%	24%	29%	17%
Not achieved (<400)	32%	76%	40%	86%	33%	72%	34%	78%
Average scores	447	342	429	279	440	365	442	335

Source: Department of Basic Education

In terms of gender, South Africa is among the few countries in which girls consistently perform better than boys in both Mathematics and Science (Figure 3.2). The gap is narrow in Grade 9 in comparison to Grade 5.

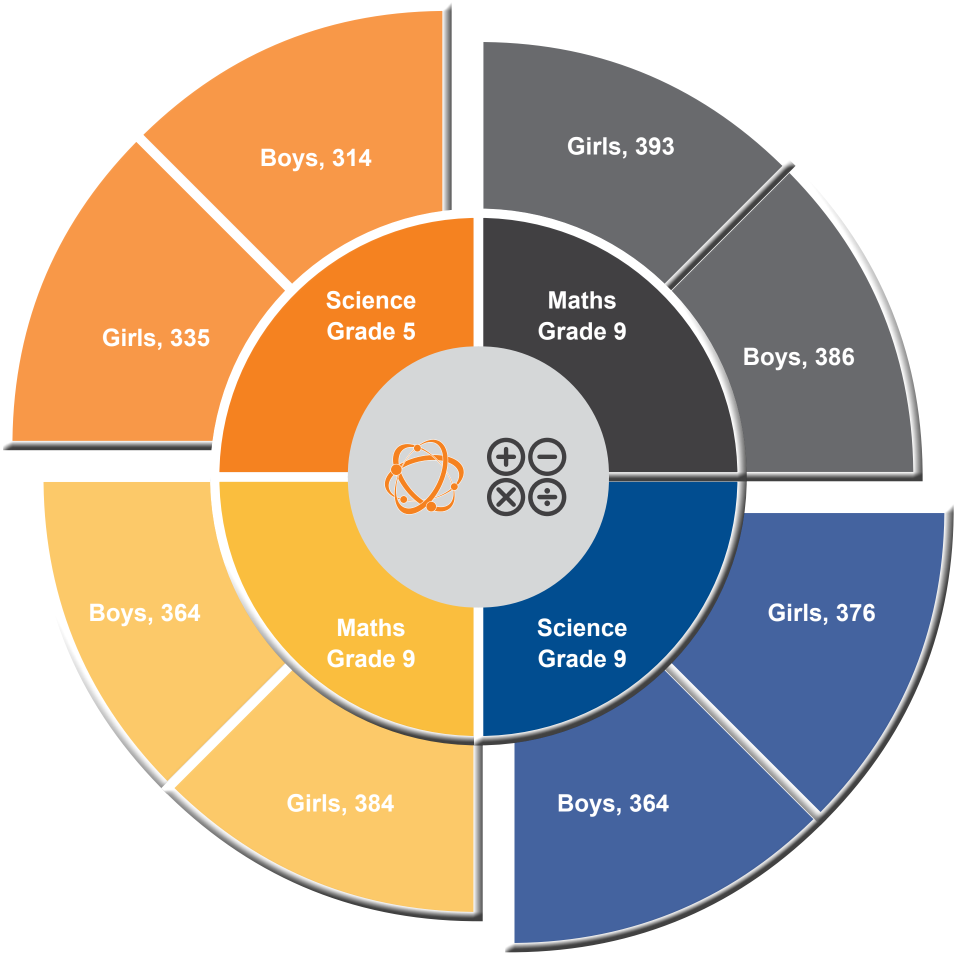


Figure 3.2: TIMSS 2019 average benchmark scores by gender
Source: International Association for the Evaluation of Educational Achievement's TIMSS 2019

The TIMSS measures proficiency in both content and cognitive domains. The cognitive domains indicate the three learning objectives by level of complexity: knowledge, knowledge application and reasoning. These three cognitive domains are applied in all subjects and grades. For the three Grade 4 Mathematics content domains, all the average scores for South African learners are below the minimum benchmark level of 400. On average, learners scored high on the content domain of data (390), followed by numbers (370) and measurements and geometry (362). Although South Africa scored lower than most benchmark countries in Table 3.11, another country that shows a similar pattern for the Grade 4 Mathematics content domains is England.

Singapore, a top-performing country, as well as Pakistan (performing lower than South Africa), shows a unique pattern in mastering numbers, followed by measurement and geometry, and data. The cognitive domain that Singapore mainly emphasises is knowing (640), followed by applying (626) and reasoning (614). This is aligned to a traditional Bloom taxonomy in which learning starts with the accumulation of knowledge, followed by other high levels of learning. England, South Korea and the USA also mainly emphasise knowledge, although reasoning scores slightly higher than knowledge application.

Table 3.11: Benchmarking of Grade 4 Mathematics benchmark scores on TIMSS 2019

			CONTENT DOMAINS			COGNITIVE DOMAINS		
		TIMSS SCORE	NUMBER	MEASUREMENT & GEOMETRY	DATA	KNOWING	APPLYING	REASONING
South Africa	Grade 5	374	370	362	390	372	375	370
England	Grade 4	556	559	545	565	563	553	554
Morocco	Grade 4	383	383	386	374	379	387	380
Pakistan	Grade 4	328	351	286	278	327	306	354
Phillipines	Grade 4	297	308	259	291	302	286	272
Russia	Grade 4	567	567	571	560	555	571	573
Singapore	Grade 4	625	635	620	613	640	626	614
South Korea	Grade 4	600	593	608	602	612	594	596
United States	Grade 4	535	542	520	533	536	537	524

Source: International Association for the Evaluation of Educational Achievement's TIMSS 2019

Russia, Morocco and South Korea show a relatively high proficiency in measurement and geometry, an area in which South African Grade 5 learners are not performing well. Along with South Africa, all other countries in Table 3.11 perform relatively poorly in measurement and geometry.

Table 3.12 introduces two further countries, Egypt and Malaysia, as they only participate at Grade 8 level and are more comparable to South Africa. Although, for some reason, South Africa's content and cognitive domains' scores are not shown in the TIMSS 2019 report, the scores for Gauteng and the Western Cape are shown. Both provinces participated for benchmark purpose in Grade 8. Although Gauteng learners perform slightly lower than those in the Western Cape, the achievement pattern remains the same in both content and cognitive domains.

Although the data domain was a strong area for South African Grade 5 learners, in Grade 8, data and probability scores were relatively low. England, on the contrary, remains relatively strong in this area. In terms of cognitive domains, in this case, South African learners are relatively strong on reasoning, followed by knowledge application and memorisation of knowledge learnt. Performance in geometry remains relatively low, although learners in North African countries (Morocco and Egypt) show relatively higher proficiency in geometry.

Table 3.12: Benchmarking of Grade 8 Mathematics benchmark scores on TIMSS 2019

			CONTENT DOMAINS				COGNITIVE DOMAINS		
		TIMSS SCORE	NUMBER	ALGEBRA	GEOMETRY	DATA AND PROBABILITY	KNOWING	APPLYING	REASONING
South Africa (Gauteng)	Grade 9	421	421	431	407	406	411	423	427
South Africa (Western Cape)	Grade 9	441	445	451	427	426	432	442	444
Egypt	Grade 8	413	414	413	417	380	416	405	411
England	Grade 8	515	519	504	509	523	510	518	512
Malaysia	Grade 8	461	458	456	466	457	451	464	462
Morocco	Grade 8	388	377	370	413	372	382	389	381
Russia	Grade 8	543	541	560	540	517	550	543	536
Singapore	Grade 8	616	611	619	619	620	614	614	620
South Korea	Grade 8	607	605	609	617	598	614	604	609
United States	Grade 8	515	520	520	499	509	522	515	507

Source: International Association for the Evaluation of Educational Achievement's TIMSS 2019

Lastly, in TIMSS, Table 3.13 shows performance in the content domains (biology, chemistry, physics and earth science) and the cognitive domains for Grade 8 Science (Grade 9 for South Africa). As benchmark participants, Gauteng and the Western Cape are shown along with the country's average performance. Despite South African learners, on average, achieving lower than a minimum TIMSS benchmark level of 400, a relatively high proficiency is observed in physics (381), followed by chemistry (372). Morocco and Egypt also emphasise chemistry and physics, although both score slightly better than South Africa. Grade 9 learners achieved a relatively low benchmark score in biology (370), which is not good in the context of future human capital towards fighting epidemics and global pandemics such as COVID-19.

The USA's Grade 8 learners show a relatively high proficiency in biology and earth science (a score of 530 for both). This is not surprising, as shown by this country's leadership in the race towards the discovery of an effective COVID-19 vaccine. This country has been at the centre of advanced medical research. That being said, Singapore's Grade 8 learners are outperforming other countries in biology with an average score of 622. About 17% of Singapore's R&D expenditure is dedicated to biomedical sciences in order to drive its goal of developing the biomedical and health sciences sector as a key pillar of its economy[3]. Whereas Singapore's Grade 8 learners' cognitive strength in science is more on knowledge (621), followed by application (608) and reasoning (595), learners in the USA are more proficient in reasoning (528), followed by knowledge application (523) and knowledge (515). A comparison of Singapore and the USA can be thought of in terms of market-pull (USA) and technology-push (Singapore) paradigms. South African Grade 9 Science learners show relatively high proficiency in knowledge application (377), followed by reasoning (362) and knowledge (361).

Table 3.13: Benchmarking of Grade 8 Science benchmark scores in TIMSS 2019

			CONTENT DOMAINS				COGNITIVE DOMAINS		
		TIMSS SCORE	BIOLOGY	CHEMISTRY	PHYSICS	EARTH SCIENCE	KNOWING	APPLYING	REASONING
South Africa	**Grade 9**	370	359	372	381	366	361	377	362
South Africa (Gauteng)	**Grade 9**	422	416	423	428	419	413	428	417
South Africa (Western Cape)	**Grade 9**	439	432	442	442	442	427	446	438
Egypt	**Grade 8**	389	381	397	394	367	396	384	378
England	**Grade 8**	517	516	512	516	517	520	515	513
Malaysia	**Grade 8**	460	463	434	475	452	442	473	459
Morocco	**Grade 8**	394	387	402	402	357	380	393	398
Russia	**Grade 8**	543	543	551	540	533	543	543	543
Singapore	**Grade 8**	608	622	616	619	562	621	608	595
South Korea	**Grade 8**	561	560	561	569	562	558	560	564
United States	**Grade 8**	522	530	509	515	530	515	523	528

Source: International Association for the Evaluation of Educational Achievement's TIMSS 2019

3.1.5 Grade 12 Mathematics and Physical Science

The 2020 NSC in gateway subjects (Table 3.14) shows the negative impact of COVID-19 on the performance of learners at schools. In comparison to 2019, the pass rate declined in all the STEM-related subjects, except for Mathematical Literacy, in which there was a slight increase in the percentage of learners passing with 30% or more (from 80.6% in 2019 to 80.8% in 2020).

3 Observatory on Health Research Systems, 2010. *Health and Medical Research in Singapore*. RAND Corporation.

There is no evidence of a high school dropout rate at matric level due to COVID-19 as the number of learners who wrote their examinations in most cases exceeded the numbers from 2019 (with the exception of Agricultural Sciences).

Table 3.14: Performance on STEM-related gateway NSC subjects

		AGRICULTURAL SCIENCES	GEOGRAPHY	LIFE SCIENCES	MATHEMATICAL LITERACY	MATHEMATICS	PHYSICAL SCIENCES
2016	Total wrote	106 386	302 600	347 662	361 865	265 810	192 618
	Achieved at 30% or above	80 184	231 588	245 070	257 881	135 958	119 427
	Percentage achieved at 30% or above	75.4	76.5	70.5	71.3	51.1	62
2017	Total wrote	98 522	276 771	318 474	313 030	245 103	179 561
	Achieved at 30% or above	69 360	212 954	236 809	231 230	127 197	116 862
	Percentage achieved at 30% or above	70.4	76.9	74.4	73.9	51.9	65.1
2018	Total wrote	95 291	269 621	310 041	294 204	233 858	172 319
	Achieved at 30% or above	66 608	200 116	236 584	213 225	135 638	127 919
	Percentage achieved at 30% or above	69.9	74.2	76.3	72.5	58	74.2
2019	Total wrote	92 680	271 807	301 037	298 607	222 034	164 478
	Achieved at 30% or above	69 132	218 821	217 729	240 816	121 179	124 237
	Percentage achieved at 30% or above	74.6	80.5	72.3	80.6	54.6	75.5
2020	Total wrote	96 155	287 629	319 228	341 363	233 315	174 310
	Achieved at 30% or above	69 916	216 467	226 700	275 684	125 526	114 758
	Percentage achieved at 30% or above	72.7	75.3	71	80.8	53.8	65.8

Source: Department of Basic Education

For the assessment of the human capital development pipeline, Table 3.15 shows a distribution of the number of learners who wrote the NSC and those who achieved 30% or above by the quantile level of the school. In 2020, about 70% of learners who wrote Agricultural Sciences are from quantile 1 and 2 schools. Therefore, quantile 1 and 2 schools are vital for the supply of university students who pursue agricultural sciences-related qualifications and are thus beneficial for food security. Most learners who write Geography are from Quantile 3 schools (26.7% in 2020 from 25.8% in 2019).

Relative to other subjects, Quantile 5 schools have a larger proportional share of the number of learners who wrote Mathematics in 2020 (18.6%). In all school types, there are more learners enrolled for Mathematical Literacy than for Mathematics. In 2020, most learners who wrote Life Sciences were based at Quintile 1 schools (24.8%), followed by Quantile 2 schools (22.9%) and Quantile 3 schools (22.8%). Enrolment of Physical Sciences is also mainly from Quintile 1 schools (25.0% in 2020), followed by Quantile 2 schools (22.5%) and Quantile 3 schools (22.3%).

In all these subjects, Quantile 0 schools (private schools that also write the NSC) represent a small proportion.

Table 3.15: Distribution of gateway NSC subject enrolment and pass by quantile level of school

		QUANTILE											
		5		4		3		2		1		0	
		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
		PERCENTAGE											
Agriculture	Wrote	1.5	1.6	3.2	2.7	22.6	23.2	31.8	31.9	38.0	38.1	2.9	2.6
	Passed at 30% or above	1.8	1.8	3.3	2.9	23.1	22.9	31.8	32.0	36.8	37.5	3.2	2.9
Geography	Wrote	12.2	11.5	12.0	11.7	25.8	26.7	24.0	23.8	22.4	23.0	3.7	3.4
	Passed at 30% or above	14.0	13.4	12.4	12.1	24.9	25.4	23.4	23.4	21.3	21.8	4.0	3.9
Life Sciences	Wrote	16.0	14.8	11.0	10.6	22.2	22.8	22.6	22.9	23.8	24.8	4.3	4.0
	Passed at 30% or above	18.6	17.3	11.1	10.6	21.2	21.6	21.6	22.3	22.6	23.6	4.9	4.7
Mathematical Literacy	Wrote	17.9	16.7	13.6	13.4	23.6	25.2	21.3	21.1	19.4	19.8	4.1	3.8
	Passed at 30% or above	20.9	19.6	14.2	13.9	22.7	23.8	20.1	20.1	17.6	18.4	4.5	4.2
Mathematics	Wrote	18.6	17.2	11.2	10.6	21.2	22.1	21.2	21.8	23.0	23.8	4.8	4.5
	Passed at 30% or above	27.5	25.7	11.9	11.3	18.4	19.2	18.0	18.4	18.2	19.5	5.9	5.8
Physical Sciences	Wrote	16.7	15.4	11.0	10.5	21.5	22.3	22.0	22.5	24.2	25.0	4.6	4.2
	Passed at 30% or above	19.9	19.7	11.3	10.9	20.6	20.8	21.0	20.9	22.2	22.8	5.0	4.9

Source: Computed from the Department of Basic Education's School Subject Report 2020

The pass rate for different types of schools is shown in Table 3.16. Quantile 5 schools perform better in most STEM-related gateway subjects, although their performance is below that of schools that write the Independent Examination Board (IEB) exams. In 2020, Quantile 1 schools performed below the national average in all the subjects shown in Table 3.16. Quantile 2 schools performed better, slightly above the national average pass rate in Agricultural Sciences (73.0% vis-à-vis 72.7%).

In both 2020 and 2019, the private schools (Quantile 0) performed better than the Quantile 4 schools. These schools improved their Mathematics pass rate (30% or above) from 67.5% in 2019 to 70.1% in 2020.

Table 3.16: Gateway NSC subjects pass rate by quantile level of school

	QUANTILE													
	5		4		3		2		1		0		TOTAL	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
	PERCENTAGE ACHIEVED AT 30% OR ABOVE													
Agriculture	89.3	83.3	78.2	76.3	76.1	72.0	74.6	73.0	72.1	71.5	84.0	81.2	**74.6**	**72.7**
Geography	92.1	88.3	83.3	77.8	77.8	71.6	78.6	74.0	76.6	71.4	87.7	87.3	**80.5**	**75.3**
Life Sciences	84.2	82.5	72.9	70.7	69.1	67.3	69.2	69.3	68.5	67.5	80.9	82.0	**72.3**	**71.0**
Mathematical Literacy	94.2	94.6	84.1	83.6	77.5	76.3	75.8	76.8	73.3	75.4	88.4	90.4	**80.6**	**80.8**
Mathematics	80.5	80.4	58.3	57.3	47.4	46.9	46.1	45.3	43.0	44.2	67.5	70.1	**54.4**	**53.8**
Physical Sciences	90.1	84.3	77.6	68.0	72.4	61.2	72.2	61.0	69.3	60.2	81.7	76.4	**75.5**	**65.8**

Source: Computed from the Department of Basic Education's School Subject Report 2020

3.2 The research system

This section identifies several countries with which South Africa may be compared using the metrics of research publications and specialisation as they are manifested in research production. The fractional count of scientific publications for South Africa and selected African countries is shown in Table 3.17.

Table 3.17: African countries ranked by fractional count of publications, 2018

COUNTRY	FRACTIONAL COUNT	WHOLE COUNT
Egypt	13 326	19 933
South Africa	13 008	20 203
Nigeria	5 602	7 928
Tunisia	5 564	7 638
Algeria	5 231	6 974
Morocco	5 956	6 353
Ethiopia	1 994	3 190
Ghana	1 275	2 360
Kenya	1 246	2 782

Figure 3.3 shows the number of publications of Egypt, South Africa and Tunisia for the period 2008–2018. Fractional counts are used when using full counting, highly for collaborative papers, which are fully counted for each party involved, ending up inflating the level of output of the participating countries in these areas. It is interesting to note that, for first time, Egypt appeared to be producing more publications than South Africa during 2018.

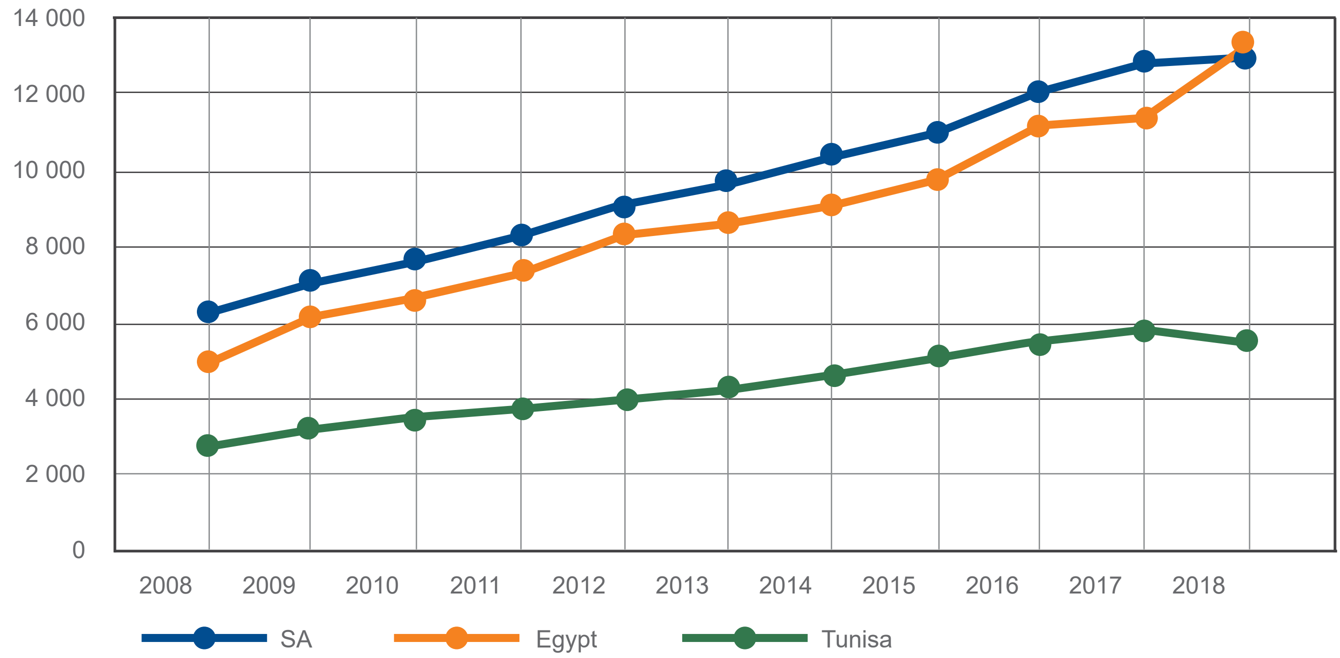


Figure 3.3: Number of fractional publications for selected African countries
Source: Scopus database and National Science Board

Table 3.18 shows the research fields with the most publications in the various countries.

Table 3.18: Research fields with the most publications in South Africa and selected countries, 2013–2019

	SOUTH AFRICA	BRAZIL	RUSSIA	INDIA	CHINA	EGYPT	NIGERIA	TUNISIA	USA	AUSTRALIA
Engineering	13 905	48 987	64 897	184 082	750 743	19 504	4 710	11 229	475 322	73 626
Environmental Science; Ecology	9 332									40 342
Agriculture		31 370								
Physics			98 672							
Chemistry				100 835	441 833	14 729			336 060	
Public Environmental Occupational Health							2 878			
Computer Science								8 525		

Source: Web of Science

Engineering appears to be among the top two disciplines in all countries, although the numbers vary from 4 000 in Nigeria to 475 000 in the USA. These statistics do not take factors like the size of the scientific system or the field characteristics into account

Table 3.19 shows the specialisation indices of the selected countries. The indicator normalises a country's share of the world output in a subfield with this country's share of the world output in science overall.[4] The index measures whether a country is publishing more or less than expected in a given subfield relative to its share of all scientific output at the world level.

4 The ratio is also known as the Research Activity Index

An indicator of approximately 1 means that the country is producing the expected number of publications relative to its total output and world output.

Table 3.19: Specialisation indices for South Africa and selected countries, 2018

	BRAZIL	RUSSIA	INDIA	CHINA	SOUTH AFRICA	USA	EGYPT	NIGERIA	TUNISIA	AUSTRALIA
Agricultural sciences	4.03	0.22	1.12	1.10	1.41	0.56	1.45	3.78	1.14	1.04
Astronomy and astrophysics	0.61	1.32	0.55	0.36	1.19	1.56	Ne	Ne	Ne	1.09
Biological and biomedical sciences	1.55	0.76	0.87	0.82	1.40	1.17	1.23	1.37	0.76	1.18
Chemistry	0.77	1.06	1.36	1.55	0.76	0.57	1.76	0.30	0.88	0.50
Computer and information sciences	0.75	0.73	1.72	1.24	0.77	0.72	0.94	0.71	2.29	0.71
Engineering	0.56	0.87	1.04	1.50	0.73	0.76	0.99	0.82	1.30	0.82
Geosciences, atmospheric and ocean sciences	0.98	1.89	0.49	0.95	1.27	1.15	0.77	1.26	0.86	1.34
Health sciences	1.20	0.45	0.59	0.55	0.89	1.43	1.06	1.03	0.65	1.37
Materials science	0.48	2.56	2.22	1.55	0.68	0.31	0.70	1.22	0.63	0.36
Mathematics and statistics	0.78	1.70	1.44	0.87	0.88	0.85	0.93	0.74	1.97	0.52
Natural resources and conservation	1.52	0.56	0.75	1.32	1.38	0.61	1.27	2.35	0.80	1.10
Physics	0.58	2.44	1.16	1.10	0.57	0.71	0.81	0.35	0.75	0.45
Psychology	0.73	0.34	0.15	0.20	1.17	2.00	0.13	0.37	ne	1.87
Social sciences	0.92	1.02	0.31	0.22	2.86	1.55	0.20	1.53	0.43	1.88

Source: Scopus database and National Science Board

South Africa shows its highest specialisation index in social sciences (2.86). No other country places such a great emphasis on social sciences. Australia, Nigeria and the USA emphasise social sciences too, but to a lesser extent. Agricultural sciences, biological and biomedical sciences, and natural resources and conservation also feature prominently in South Africa.

Table 3.20 shows the countries collaborating with South Africa and the selected countries.

Collaboration is expected to affect and be affected by the counties' specialisation. The USA appears to be among the top two collaborating countries in all selected countries, with the exeption of Tunisia. China appears as a major collaborator with the USA and Australia.

Table 3.20: Collaborating countries with South Africa and selected countries, 2013–2019

	USA	ENGLAND	GERMANY	SAUDI ARABIA	SOUTH AFRICA	FRANCE	CHINA
South Africa	26 812	17 492					
Brazil	60 474	22 249					
Russia	34 040		31 002				
India	56 068	20 133					
China	345 543	75 071					
Egypt	13 653			24 052			
Nigeria	4 759				4 268		
Tunisia				4 184		12 953	
USA		217 915					345 591
Australia	111 368						75 029

Source: Web of Science

3.3 Innovation-friendly environment

This sub-section gives specific attention to entrepreneurship, drawing on two sources, the annual Global Entrepreneurship Monitor (GEM) and the European Innovation Scoreboard (EIS). The EIS incorporates the sentinel GEM indicator, as well as total early-stage entrepreneurial activity (TEA) as a component of the contextual indicators that inform business and entrepreneurship. These contextual indicators allow the comparisons shown in Table 3.21. The EIS notes that the overall employment structure of the South African economy is similar to that of the European Union (EU), but that foreign direct investment (FDI) inflows and R&D spending by companies are on the low side. In contrast, the TEA is high, suggesting latent endeavour, despite otherwise unfavourable conditions, including slow growth and governance issues.

Table 3.21: Entrepreneurial environment in South Africa and the European Union

	SOUTH AFRICA	EUROPEAN UNION
Performance and structure of the economy		
GDP per capita, purchasing price parity (PPP) (international $)	13 400	41 800
Change in GDP (%)	-0.5	2.2
Employment share in agriculture	5.3	4.7
Employment share in industry	23.3	25.0
Employment share in services	71.4	70.3
Manufacturing share in total value added	12.4	15.8
Business and entrepreneurship		
TEA	10.9	6.7
FDI net inflows (percentage of GDP)	0.94	2.63
Top R&D spending firms per million population	0.3	16.2
Average R&D spending (million Euros)	54.2	223.6
Number of unicorns	2	27
Buyer sophistication (1 to 7 best)	3.96	3.73
Governance and policy framework		
Ease of starting a business	66.3	76.5
Basic school entrepreneurial education and training	1.74	1.93
Government procurement of advanced technology products	3.02	3.50
Rule of law (-2.5 to 2.5 best)	-0.01	1.06

Source: European Innovation Scoreboard 2020

4. SCIENCE, TECHNOLOGY AND INNOVATION INVESTMENTS

The growth of the NSI depends strongly on STI investments from both the public and private sectors. In some instances, investment is accompanied by know-how as is the case with foreign direct investment by research- and innovation-intensive multinational corporations. R&D expenditure is used as a proxy for R&D investments by various actors of the NSI. The pattern of investment by the NRF, TIA, business sector and venture capitalists is also analysed.

4.1 Science, technology and innovation funding and support

4.1.1 Expenditure on research and development

It is vital to consider the distribution of R&D expenditure across basic research, applied research and experimental development. Basic or blue-sky research is open-ended, with high-levels of uncertainty, although it may be conducted with a specific goal in mind. Applied research is generally intended to address a specific practical aim or objective, while experimental development is directed toward generating new products or processes[5]. Table 4.1 shows the change in this distribution.

Table 4.1: Expenditure by type of research

	BASIC	APPLIED	EXPERIMENTAL
2010/11	23.9	39.8	36.3
2011/12	24.5	42.3	33.2
2012/13	25.3	46.3	28.4
2013/14	23.8	47.3	28.9
2014/15	24.3	48.8	26.9
2015/16	25.4	47.5	27.1
2016/17	26.7	47.8	25.5
2017/18	26.4	53.3	20.3
2018/19	28.2	52.5	19.3

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

The following has been observed:

- A modest rise in the proportional expenditure on basic research
- A modest rise in the proportional expenditure on applied research
- A sharp decline in the proportional expenditure on experimental development

Appendix C provides the distribution across the fields of research and development.

5 OECD, 2015. Frascati Manual: Guidelines for collecting and reporting data on research and experimental development. Available at: http://www.oecd.org/sti/frascati-manual-2015-9789264239012-en.htm.

The following are observed:

- A secular decline in expenditure on natural sciences, technology and engineering, which is naturally compensated for by the rise in expenditure on social sciences and humanities, the proportion of which has more than doubled over the period. The share of the humanities remains very low.
- In the natural sciences, technology and engineering, the fields that show the strongest declines are applied sciences and technologies, and engineering sciences.
- Equally notable is a strong rise in expenditure on medical and health sciences, which has more than doubled.
- Although their shares are small, both the mathematical and physical sciences have seen a doubling in expenditure.

Society is seriously affected by the human immunodeficiency virus (HIV) and tuberculosis (TB), and the rise in research in the medical and health sciences, and the social sciences is a response to this challenge.

The data in Table 4.2 suggests that South Africa is an outlier in expenditure on the social sciences, being two standard deviations out from the global average. The average for the 14 countries is 8%, clearly demonstrating the outlier status. It is fair to state that, by world norms, South Africa's expenditure on research in the social sciences is very high.

Table 4.2: Expenditure on fields of R&D in the global context

	SCIENCE AND ENGINEERING	SOCIAL SCIENCES	MEDICAL AND HEALTH SCIENCES
	SOUTH AFRICA		
	74.0	**23.7**	**19.5**
	WORLD		
Average	80.1	9.6	11.3
Median	82.8	8.8	9.3
Standard deviation	16.2	6.5	8.5

4.1.2 National Research Foundation

The National Research Foundation supports various research activities through instruments such as infrastructure grants, institutional grants (e.g. research chairs), national facilities, researchers' mobility grants, scholarships and fellowships, and professional development grants. Figure 4.1 shows a five-year trend on grants claimed by the recipients (excluding bursaries, scholarships and fellowships). This trend has been flat in the medium term, with a significant decline of 18.1% from 2019 to 2020.

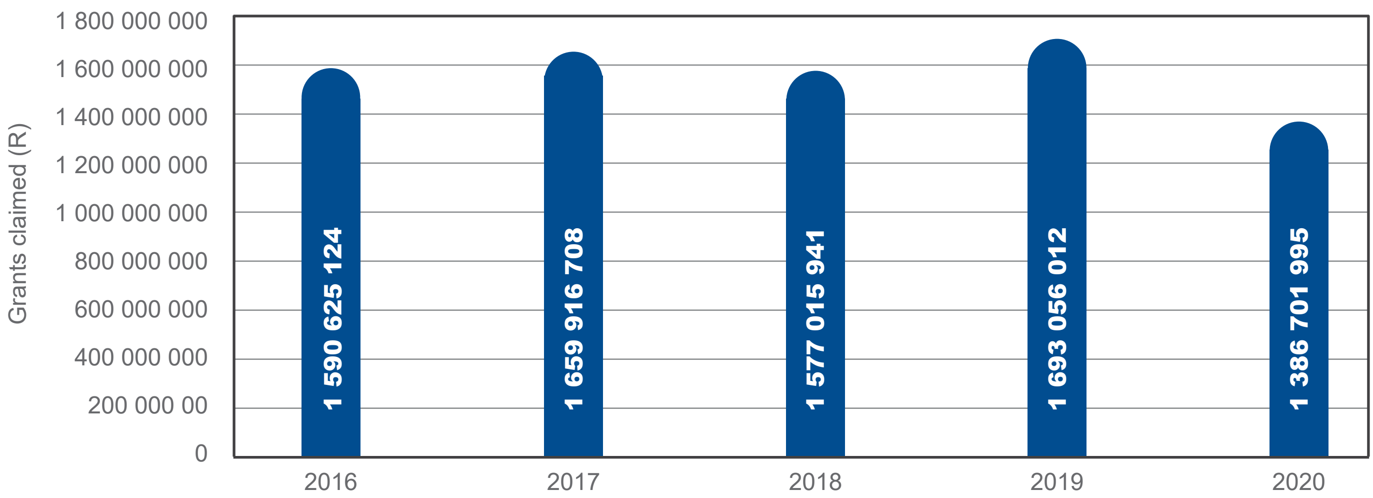


Figure 4.1: Annual National Research Foundation grants claimed
Source: National Research Foundation Information Portal

A trend of research infrastructure funding claims from the NRF is shown in Figure 4.2. This oscillating pattern of infrastructure funding claims is explained in the NRF's 2019/20 annual report as follows:

> "Investment in research infrastructure through the National Equipment Programme is only possible in alternate years due to financial constraints. This has resulted in users of the funded equipment declining from 2 996 in 2018/19 to 2 234 in 2019/20, with a corresponding number of research publications dropping from 682 to 579."

This signals a constrained research system as is evident by the declining number of overall research grants claimed.

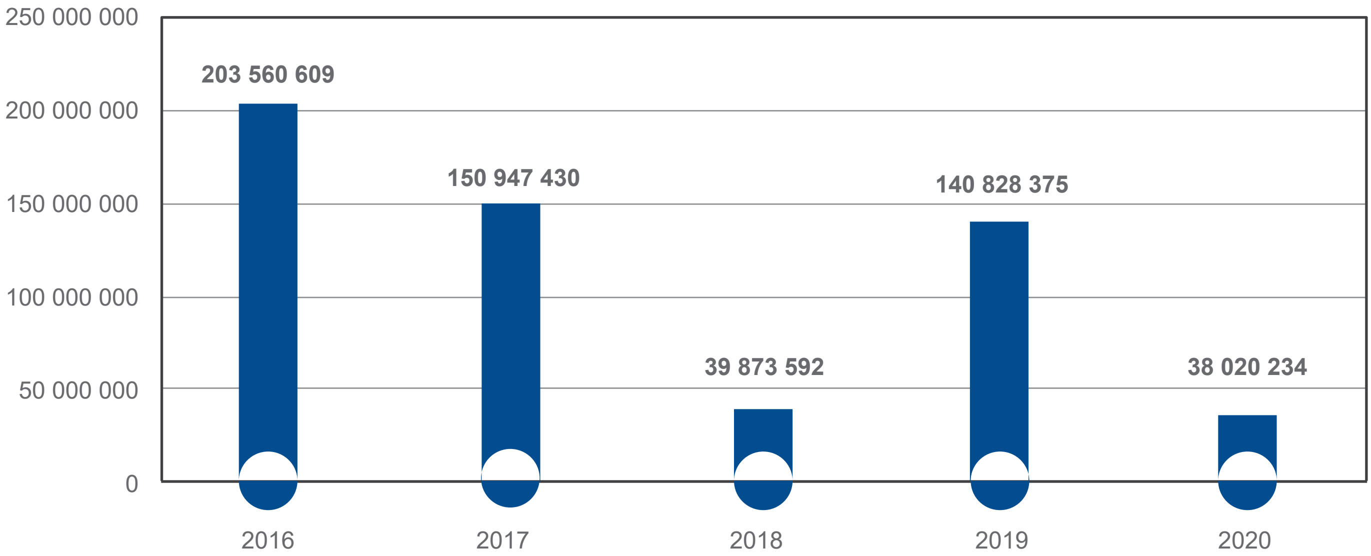


Figure 4.2: Trend in research infrastructure funding claims
Source: National Research Foundation Information Portal

The impact of declining research infrastructure grants on various research fields is depicted in Table 4.3. Physical and chemical sciences remain the major beneficiaries of research infrastructure support, although they are also impacted by reduced infrastructure funding. The least funded research field is information and computer science.

Table 4.3: Distribution of NRF research infrastructure grants by field

	2016	2017	2018	2019	2020
Agricultural sciences	12 597 000	8 168 926	10 374 832	0	1 836 096
Biological sciences	32 014 630	54 309 362	9 474 111	30 969 325	3 352 120
Chemical sciences	44 052 320	13 337 716	6 622 600	33 384 715	10 873 276
Earth and marine sciences	3 717 048	7 690 768	1 840 517	4 142 186	228 938
Engineering sciences	13 895 490	21 973 270	0	21 844 008	843 784
Health sciences	7 600 000	12 833 622	646 793	2 084 170	394 782
Information and computer science	0	794 134	0	856 462	19 038
Basic medical sciences	8 744 800	5 930 222	3 366 834	11 116 634	3 093 560
Physical sciences	64 496 041	25 742 900	5 448 697	36 430 875	14 440 244
Technologies and applied sciences	400 280	0	2 099 208		3 343 397

Source: National Research Foundation Information Portal

4.1.3 Technology Innovation Agency

The TIA was established in 2008 through the Technology Innovation Agency Act (Act No. 26 of 2008) as an amalgamation of several entities and programmes, including the Innovation Fund, the Tshumisano Trust, the Advanced Manufacturing Technology Strategy Implementation Unit at the Council for Scientific and Industrial Research (CSIR), BioPAD, Lifelab, Cape Biotech and PlantBio. This background provides the context for the TIA's ongoing focus on the bio-economy (Table 4.4). As shown, most of the TIA's project expenditure in 2019/20 went to the Bio-economy Division (R187 million or 41.7%). The Technology Platforms Programme (TPP) contributes a large share of expenditure within this division (44.7% in 2019/20 and 57.6% in 2018/19). The Programmes Division also contributes a large share of all the TIA's projects expenditure, with the Technology Stations Programme (TSP) being the largest contributor. In addition to the bio-economy, other sectors supported by the TIA through the Sector Funding Division are advanced manufacturing, energy, ICT and natural resources.

Table 4.4: TIA expenditure per programme

	2018/19	2019/20
	R MILLION	
Bio-economy Division	**115.5**	**187.0**
Agriculture	19.0	50.1
Health	7.8	21.4
Technology Platforms Programme	66.5	83.6
Technology Innovation Cluster Programme	22.2	31.9
Sector Funding Division	**77.9**	**83.8**
Advanced Manufacturing	22.5	18.3
Energy	20.0	18.9
ICT	15.1	25.9
Natural Resources	20.3	20.7
Programmes Division	**217.1**	**177.5**
Seed Programme Fund	38.5	32.7
Technology Stations Programme	158.8	137.0
Innovation Skills Development	12.7	4.0
Global Cleantech Innovation Programme	4.9	2.4
Youth Technology Innovation Fund	2.2	1.4
Total TIA programmes funding	**410.5**	**448.3**

Source: Technology Innovation Agency's 2019/20 Annual Report

Table 4.5 highlights the TPP's performance over the last five years. According to the TIA, the main remit of the platforms is to support local innovation in the form of technical support for products, prototypes, diagnostics and drug development. The TPP is equipped with state-of-the-art equipment and is resourced with highly competent individuals in specialised fields to develop new products and processes for industry and R&D-led entrepreneurs by serving as technology nurseries.

Table 4.5 shows that most of the projects supported by the TIA are at Technology Readiness Level (TRL) 3–7, which entails activities such as experimental proof of concept, technology validation, technology demonstration and system prototype demonstration. Most of the projects funded are based at the universities and there was an increased focus on small, medium and micro enterprises (SMMEs) in the 2019/20 financial year. Although science councils are expected to carry out their activities at higher TRLs in comparison to universities, their share of funding was only 5% in 2019/20 and they had no funding from the TPP in 2018/19. Due to the location of this programme within the TIA, its main focus areas are health (62% of funding in 2019/20) and industrial biotechnology (24%).

Table 4.5: Projects supported through the TIA's Technology Platform Programme

	2015/16	2016/17	2017/18	2018/19	2019/20
Project TRL					
1–2	29%	19%	15%	14%	20%
3–7	65%	63%	66%	66%	67%
8–9	6%	11%	9%	10%	9%
Other (work spanning multiple TRLs)	–	7%	10%	10%	4%
Funding by type of organisation					
Private	28%	36%	12%	10%	14%
University	32%	31%	67%	83%	49%
Science council	8%	7%	6%	–	5%
Government	7%	5%	3%	6%	3%
SMME	3%	3%	5%	–	12%
Focus area					
Health	50%	48%	56%	64%	62%
Agriculture	11%	7%	8%	4%	8%
Industrial biotechnology	38%	41%	34%	26%	24%
Food and beverage	1%	2%	1%	4%	4%
Other	–	2%	1%	2%	2%
Total number of projects	**102**	**119**	**113**	**98**	**138**

Source: Technology Innovation Agency's 2019/20 Annual Report

4.2 Firm investments

The investments that are discussed in this section are venture capital, BERD and R&D human resources in the business sector.

4.2.1 Venture capital investment

Venture capital is an important source of funding for new enterprises, particularly small innovative and technology-based firms.

Seed and start-up capital represent the early-stage orientation of venture capital: the extent to which venture capital is supporting new ventures. In 2019, seed and start-up capital made up 40.2% by value of deals and 53.8% by number of deals (see Table 4.6). This was a lower share than in 2018 when seed and start-up capital made up 45.9% by value of deals and 58.9% by number of deals.

Table 4.6: Venture capital investments' contribution by stage of deal

	INVESTMENT BY VALUE	INVESTMENT BY NUMBER OF DEALS
Seed capital	3.7%	7.5%
Start-up capital	36.5%	46.3%
Later-stage financing	23.6%	14.7%
Growth capital	30.9%	28.0%
Buy-out capital	2.0%	2.0%
Rescue/turnaround	3.0%	1.1%
Replacement capital	0.3%	0.4%

Source: Southern African Venture Capital Association's 2020 venture capital industry survey

As shown in Table 4.7, over the last decade, there has been a steady increase in the value of investments and the number of deals, with the rate of growth rising most rapidly after 2015. The value of investments rose by 15% in nominal terms in 2019 in comparison with the previous year, while the number of investments rose by 21% from 134 to 162.

Table 4.7: Venture capital investments per annum

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Investments per year – value (R' millions)	194	211	288	183	273	372	933	968	1 067	1 230
Investments per year – number of deals	3	11	8	19	67	69	116	147	134	162

Source: Southern African Venture Capital Association's 2020 venture capital industry survey

As shown in Table 4.8, manufacturing, and food and beverage were the two leading sectors, accounting for a little over a quarter by value of all venture capital investments (26.5%) and one-sixth by number of deals (16.2%). Business products and services accounted for approximately one-tenth by value of investments (10.9%) and approximately one-seventh by number of deals (14.5%). Investments were widely spread over the other sectors. None of the other sectors attracted a significant share of investment or a significant share of the number of deals.

Table 4.8: Venture capital investment's number of deals by sector, 2019

	BY VALUE	BY NUMBER OF DEALS
Manufacturing	13.8%	9.3%
Food and beverage	12.7%	6.9%
Business products and services	10.9%	14.5%
Medical devices and equipment	8.3%	6.4%
Fintech specific	6.9%	9.8%
Software	6.2%	9.6%
Health	6.2%	5.6%
Consumer products and services	6.1%	9.9%
Financial services	5.3%	4.2%
Energy	4.6%	2.7%
Electronics/instrumentation	3.8%	3.5%
Agriculture	3.4%	3.5%
Telecommunications	2.4%	2.2%
Life sciences	2.2%	1.1%
eCommerce	2.2%	4.2%
Media, entertainment and gaming	1.3%	1.0%
Biotechnology	1.3%	1.1%
Security technology	1.1%	1.9%
Retailing and distribution	0.8%	1.8%
Mining, minerals and chemical processing	0.5%	0.8%

Source: Southern African Venture Capital Association's 2020 venture capital industry survey

The percentage shares of venture capital investments by sector were largely similar in 2019 in comparison with the previous year (Table 4.9). However, there was one notable exception: The share of venture capital investments in the energy sector declined by more than half, from 10.2% in 2018 to 4.6% in 2019.

Table 4.9: Value of venture capital investments by sector

	2019	2018
	PERCENTAGE SHARE	
Manufacturing	13.8	14.2
Food and beverage	12.7	12.3
Business products and services	10.9	7.2
Medical devices and equipment	8.3	10.5
Fintech specific	6.9	6.4
Software	6.2	5.2
Health	6.2	5.8
Consumer products and services	6.1	5.4
Financial services	5.3	6.2
Energy	4.6	10.2
Electronics and instrumentation	3.8	2.2
Agriculture	3.4	0.9
Telecommunications	2.4	1.5
Life Sciences	2.2	3.8
eCommerce	2.2	1.3
Media, entertainment and gaming	1.3	1.9
Biotechnology	1.3	1.2
Security technology	1.1	0.4
Retailing and distribution	0.8	2.9
Mining, minerals and chemical processing	0.5	0.5

Source: Southern African Venture Capital Association's 2019 and 2020 venture capital industry surveys

The steady increase in venture capital investments suggests that there is considerable activity on the part of new technology-based innovative firms and that such activity has been increasing. However, at this stage, there is a lack of data on such new entrants.

4.2.2 R&D expenditure and funding in the business sector

Table 4.10: R&D expenditure by the business sector

	BERD (CONSTANT 2010 RAND VALUES)
	R' 000
2009/10	11 139 271
2010/11	10 059 009
2011/12	9 822 399
2012/13	9 424 677
2013/14	9 896 243
2014/15	10 576 214
2015/16	10 452 748
2016/17	10 432 079
2017/18	10 632 765
2018/19	9 321 444

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

There was a significant decline – a little over 12% – in R&D expenditure by the business sector in 2018/19 compared with the previous year (Table 4.10).

Table 4.11: Business sector R&D expenditure as a percentage of GERD

	BERD AS A PERCENTAGE OF GERD
2009/10	53.2
2010/11	49.7
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

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

In 2018/19, R&D expenditure by the business sector was lower than at any other point in the last decade.

As shown in Table 4.11, the business sector's share in GERD has been declining consistently since 2009/10. The business sector's share in GERD in 2018/19 was 39.3%. A decade earlier, its share was 53.2%.

In addition to declining expenditure on R&D in the business sector, the business sector funding of R&D in other sectors declined (Table 4.12). The science councils and higher education institutions both received significantly less funding from the business sector for R&D in 2018/19.

Table 4.12: Business-funded R&D by sector

	TOTAL	GOVERNMENT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NON-PROFIT
	R'000					
2009/10	8 907 527	2 326	120 528	609 250	8 142 996	32 427
2010/11	8 128 246	2 406	198 206	367 340	7 528 667	31 627
2011/12	8 663 105	1 355	67 614	505 510	8 056 545	32 081
2012/13	9 152 042	11 552	135 729	577 527	8 402 340	24 894
2013/14	10 615 902	1 759	419 469	588 598	9 552 717	53 359
2014/15	11 981 974	290	222 892	885 280	10 810 428	63 084
2015/16	12 578 499	41 109	326 648	770 448	11 384 710	55 585
2016/17	14 045 892	1 261	483 166	906 651	12 586 109	68 705
2017/18	16 066 846	519	354 820	679 563	14 963 198	68 747
2018/19	14 534 123	4 614	206 648	463 413	13 787 512	71 937

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Overall, the business sector's funding of R&D outside the business sector in 2018/19 (R746.6 million) declined significantly from 2017/18 (R1.103 billion), a decline of 32%.

Business sector funding for R&D is very largely concentrated on funding R&D in the business sector itself (Table 4.13). Moreover, this concentration has been increasing. In 2018/19, a little over 5% of business sector funding for R&D was allocated to the other sectors.

Table 4.13: Proportional business-funded R&D by sector

	GOVERNMENT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NON-PROFIT
2009/10	0.0%	1.4%	6.8%	91.4%	0.4%
2010/11	0.0%	2.4%	4.5%	92.6%	0.4%
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%

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Table 4.14: Foreign-funded R&D in the business sector

	FOREIGN-FUNDED BUSINESS SECTOR R&D
	R'000
2009/10	1 538 917
2010/11	1 442 334
2011/12	1 562 277
2012/13	1 898 865
2013/14	1 226 966
2014/15	1 418 823
2015/16	1 532 766
2916/17	1338 662
2017/18	474 762
2018/19	400 462

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

As shown in Table 4.14, there has been a notable decline in the capacity of the business sector to attract foreign funding for R&D. There was a particularly significant decline in 2017/18. In 2018/19, there was a further decline of 16% from the previous year.

Table 4.15: Proportional foreign-funded R&D in the business sector

	PERCENTAGE OF BUSINESS SECTOR'S SHARE OF FOREIGN-FUNDED R&D
2009/10	60.6
2010/11	59.0
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

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

There has been a very significant decline in the business sector's share of foreign-funded R&D in South Africa (Table 4.15). Whereas a decade ago, some 60% of foreign funding for R&D in South Africa was destined for the business sector, in 2018/19, this was only 10%.

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. As Table 4.16 shows, in 2010, financial intermediation, real estate and business services accounted for a little more than a third of all business sector expenditure in R&D (33.9%). In 2019, this was the largest sector (44.3%).

Table 4.16: Proportional business sector R&D expenditure by industry

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Agriculture, hunting, forestry and fishing	1.9	1.6	2	2.7	3.1	3.5	3.5	3.2	2.5	3.9
Mining and quarrying	4.5	10.5	12.9	14.7	14.2	10.1	8.8	7.2	6.9	12.1
Manufacturing	38.8	35.7	33.9	32.9	32.2	33.9	32.2	27.8	28.2	21.9
Electricity, gas and water supply	8.6	5.3	4.7	3.6	3	4.1	3.2	3.7	4	4.9
Construction	0	0	0.1	0.1	0.1	0	0	0	0	0.1
Wholesale and retail	3.9	6.2	5.2	1.7	0.9	0.6	0.3	0.4	0.5	0.7
Transport, storage and communication	3.7	3.5	4.6	4.4	3.8	4.8	6.5	10.4	6.2	7.7
Financial intermediation, real estate and business services	33.9	33.1	34.8	37	40.1	40.3	42.8	44.3	48.8	44.3
Community, social and personal services	4.7	4.1	1.6	2.8	2.6	2.7	2.7	2.9	2.8	4.4
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Human Sciences Research Council and Department of Science and Innovation's 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 steady decline in the share of the manufacturing sector. In 2010, manufacturing was the leading sector in business sector expenditure on R&D (38.8%). In 2019, the share of the manufacturing sector was (21.9%), less than half that of financial intermediation, real estate and business services.

While R&D in high-technology manufacturing as a percentage share of R&D in total manufacturing increased in 2018/19 (15.4%), the general trend has been for this share to decline (Table 4.17). Some two-thirds of all R&D in manufacturing is in the medium-technology sectors. This share has tended to decline, and it declined further in 2019 (65.1%). The most significant declines have been in petroleum products, chemicals, rubber and plastic.

By contrast with the high- and medium-technology sectors, the share of the low-technology sectors in total manufacturing R&D has been increasing. Initially well below the high- and medium-technology sectors, low-technology manufacturing now accounts for a significantly higher share of total manufacturing R&D than is accounted for by high-technology manufacturing.

Overall, R&D data for the manufacturing sector does not show a tendency to become more technology-intensive; rather the reverse. The data for 2018/19 underlines this trend.

Table 4.17: Percentage share of R&D expenditure in the manufacturing sector

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
	PERCENTAGE									
High-technology	**13.7**	**16.4**	**18.0**	**18.9**	**19.6**	**15.7**	**12.8**	**15.3**	**14.0**	**15.4**
Radio, television, instruments, watches and clocks	13.7	16.4	18.0	18.9	19.6	15.7	12.8	15.3	14.0	15.4
Medium-technology	**78.2**	**72.8**	**69.5**	**67.7**	**66.4**	**71.2**	**73.7**	**73.8**	**72.7**	**65.1**
Petroleum products, chemicals, rubber and plastic	40.7	33.3	38.9	32.8	33.1	40.8	40.5	41.3	37.8	25.3
Other non-metal mineral products	2.8	2.4	2.0	1.4	1.4	1.1	0.6	0.9	0.6	1.4
Metals, metal products, machinery and equipment	7.6	6.7	11.1	16.8	16.4	13.5	14.9	12.6	13.0	16.6
Electrical machinery and apparatus	3.4	5.8	8.7	9.0	6.7	6.7	8.6	11.1	14.2	11.8
Transport equipment	23.7	24.6	8.7	7.7	8.8	9.1	9.1	7.8	7.1	10.0
Low-technology	**8.1**	**10.8**	**12.5**	**13.4**	**14.1**	**13.1**	**13.5**	**10.9**	**13.3**	**19.5**
Food, beverages and tobacco	3.8	6.2	8.0	9.2	9.0	8.1	8.5	8.0	10.2	15.7
Textiles, clothing and leather goods	0.4	0.1	0.0	0.1	0.8	0.8	0.2	0.2	0.5	0.4
Wood, paper, publishing and printing	2.6	3.0	2.3	1.5	1.6	1.6	2.2	2.1	2.0	2.4
Furniture and other manufacturing	1.4	1.6	2.3	2.7	2.6	2.6	2.7	0.6	0.6	1.0

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

4.2.3 R&D personnel in the business sector

Table 4.18: R&D personnel full-time equivalents in the business sector

	NUMBER OF BUSINESS SECTOR R&D PERSONNEL (FTE)
2009/10	12 025
2010/11	10 205
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	12 952
2018/19	11 691

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Reflecting declining expenditure on R&D in the business sector, the numbers employed in R&D in the business sector declined by 10% in 2018/19 compared with the previous year (Table 4.18).

While the numbers employed in R&D in the business sector have, over the decade, held up better than expenditure, there has been no clear growth trend. The numbers employed in R&D in the business sector in 2018/19 are below those of a decade ago.

Over the last decade, business sector expenditure in R&D has stagnated and funding for R&D has lagged behind other sectors. Consequently, the business sector's share of R&D and share of the funding of R&D have been declining. Moreover, foreign funding of R&D in the South African business sector has seen a significant decline. All these trends were evident in 2018/19 when there were significant declines in all input expenditure measures compared to 2017/18. There was also a notable decline in 2018/19 in the numbers employed in R&D in the business sector.

5. INNOVATION ACTIVITIES

This chapter captures innovation activities that include innovators and intellectual property.

5.1 Innovation in agricultural sector businesses

To remain competitive and address the multiple challenges that innovation faces, such as high input costs, climate change and increased competition, the agricultural sector needs to be innovative in a globally competitive industry. This section discusses the results from the business innovation survey of the South African agricultural sector. The firms that were surveyed are from the agriculture, forestry and fisheries sub-sectors.

Level of innovation

In 2016–2018, 61.7% of agricultural firms were innovative (see Figure 5.1). The percentage of innovation-active firms was 62%. Only 0.3% of firms abandoned their innovation activities.

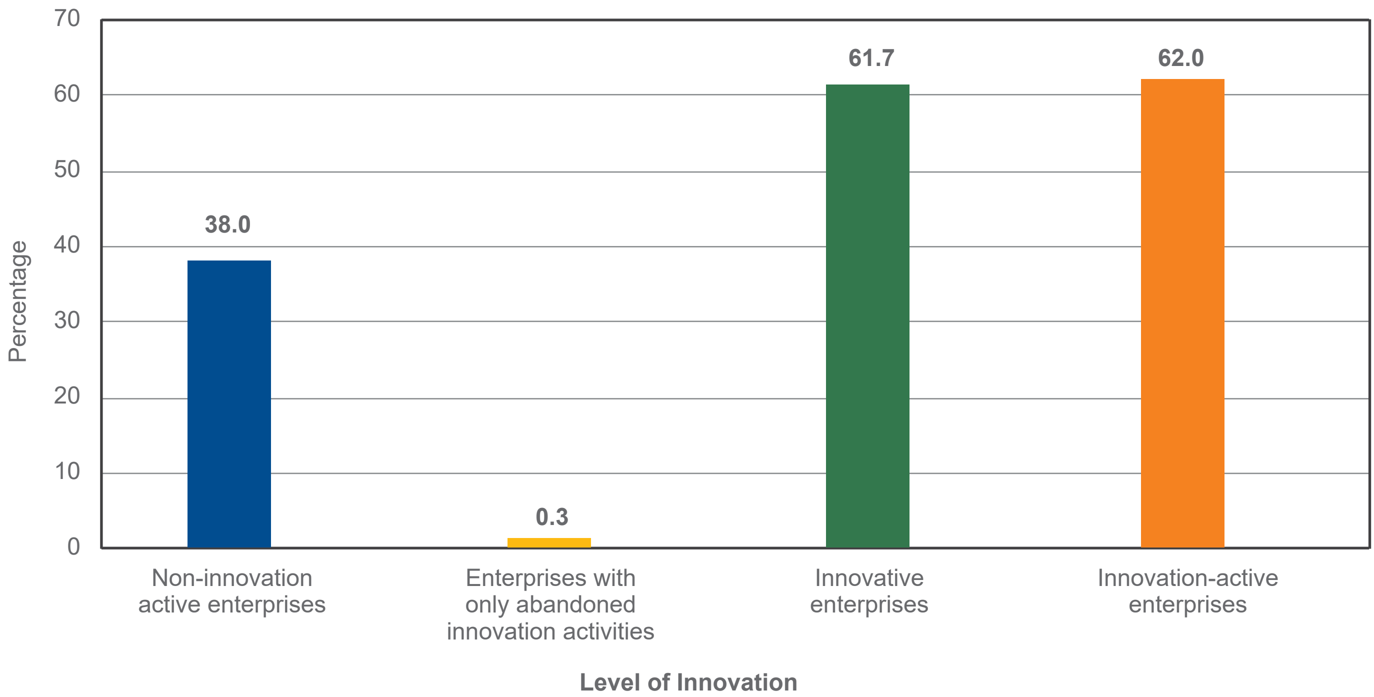


Figure 5.1: Percentage of agriculture sector businesses engaged in innovation activities, 2016–2018
Source: Centre for Science, Technology and Innovation Indicators' 2016–2018 Innovation Performance in Agriculture

However, the data does not show if the firms were engaged in incremental, imitation or radical innovations. Previous business innovation surveys in South Africa revealed that the dominant form of innovation among firms is incremental innovations.

Types of firm-level innovations

As shown in Figure 5.2, businesses were most likely to introduce new processes than products. During this period, 47.9% of businesses were process innovators and 42.2% were product innovators. Agriculture is a mature, low-technology industry that tends to focus on process innovations to improve yields, reduce costs or reduce environmental impacts. This is an important consideration because product innovation tends to lead to increased employment compared to process innovation[6].

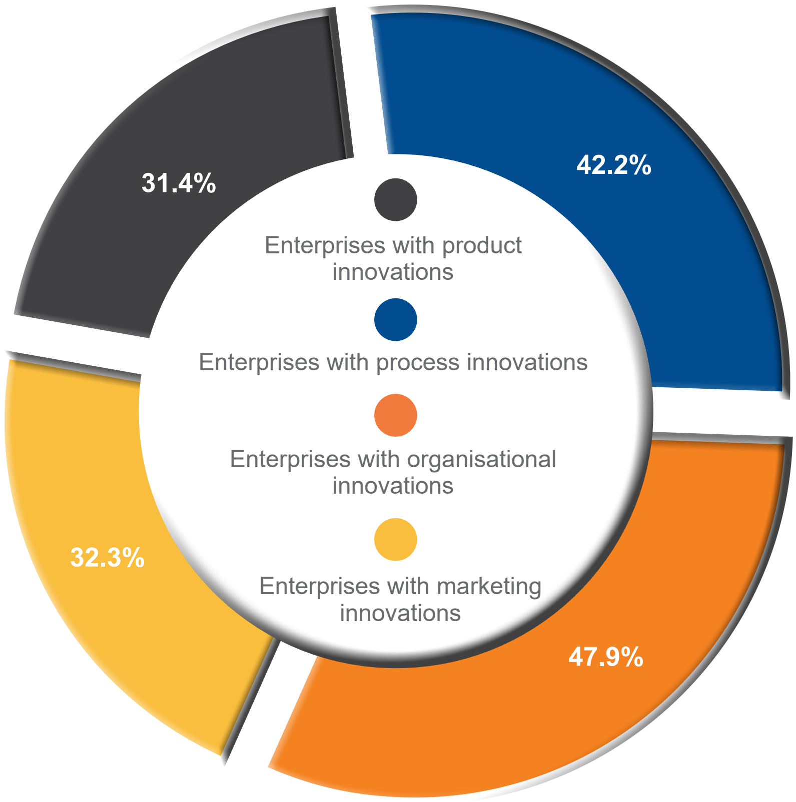


Figure 5.2 Different types of innovation among agricultural enterprises
Source: Centre for Science, Technology and Innovation Indicators' 2016–2018 Innovation Performance in Agriculture

Figure 5.2 shows that there is not much difference in engagement between organisational and marketing innovations.

Businesses innovating in-house

In pursuit of their innovation efforts, businesses can either undertake their innovation activities in-house (internally) or source goods and services from various external partners. Table 5.1 shows that 51% of innovation-active firms conduct their product innovations in-house and 26% adopt and modify goods and services that have been developed by others.

6 Edquist, C. and Chaminade, C., 2006. Industrial policy from a systems-of-innovation perspective. *EIB papers*, 11(1), pp.108–132.

Table 5.1: Strategies for the development of product innovations

	PERCENTAGE OF INNOVATION-ACTIVE FIRMS
Main own business	51%
Other businesses in your business group	1%
Your business with other businesses or institutions	18%
Your enterprise by adapting or modifying goods or services originally developed by other enterprises	26%
Mainly other enterprises or institutions	3%
Non-responsive enterprises	1%

Source: Centre for Science, Technology and Innovation Indicators' 2016–2018 Innovation Performance in Agriculture

5.2 Intellectual assets

Table 5.2 shows the number of patents granted to local and foreign inventors domestically by the CIPC for the period 2008–2018. South African applicants are shown to receive between 9% and 12.1% of the total patents awarded by the CIPC. It should be emphasised that, in other foreign countries, the majority of patents are awarded to local inventors (with the exemption of countries with small populations).

Table 5.2: Patent grants by the CIPC to South Africans and foreigners

	TOTAL PATENTS	TOTAL PATENTS BY SOUTH AFRICANS	TOTAL PATENTS BY NON-SOUTH AFRICANS	LOCAL PATENTS TOTAL
2008	**7 713**	936	6 777	12.1
2009	**7 290**	840	6 450	11.5
2010	**6 958**	871	6 087	12.5
2011	**5 437**	623	4 814	11.4
2012	**6 314**	733	5 581	11.6
2013	**4 875**	520	4 355	10.6
2014	**5 131**	465	4 666	9.0
2015	**4 557**	436	4 121	9.5
2016	**4 607**	446	4 161	9.6
2017	**5 504**	609	4 895	11.0
2018	**7 262**	711	6 551	9.7

Source: Companies and Intellectual Property Commission

Figure 5.3 shows the main countries from which inventors apply for patents in South Africa. US inventors appear to be the most dominant group, with 2 053 applications during 2018. South Africa had only 617 applications. Germany and the UK followed with 603 and 522 applications, respectively.

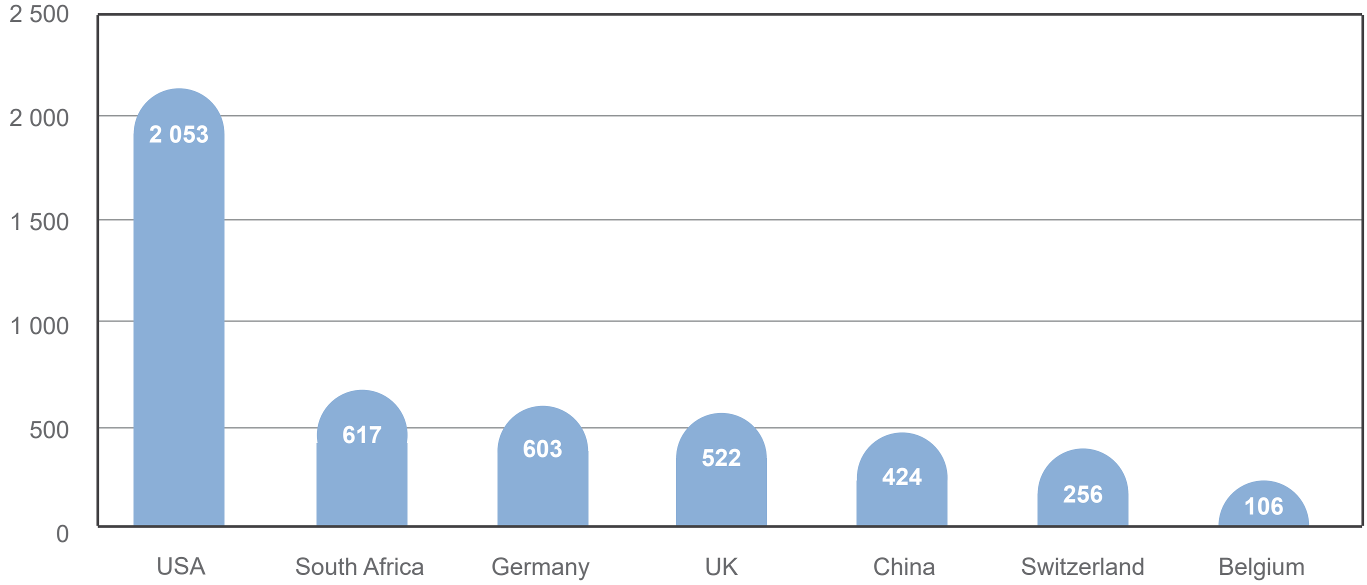


Figure 5.3: Main patent applicants at CIPC 2018
Source: World Intellectual Property Organisation's IP Statistics Data Centre

Table 5.3 shows the different types of patents granted to South Africans during the period 2010–2019. Utility patents are the main patents granted to South Africans. During 2019, 182 patents were granted to South Africans. The number of South African patents filed at the USPTO increased significantly in 2019 compared with the previous year. However, following a decline in 2018, the number of South African patents in 2019 was only marginally higher than in 2017.

Table 5.3: Different types of patents granted to South Africa by the USPTO

	UTILITY	DESIGN	PLANT	REISSUE	TOTAL
2019	182	30	10	2	**224**
2018	145	23	4	1	**173**
2017	182	31	6	0	**219**
2016	181	21	13	0	**215**
2015	166	29	4	0	**199**
2014	152	26	2	1	**181**
2013	161	20	0	0	**181**
2012	142	14	1	1	**158**
2011	123	19	2	0	**144**
2010	116	23	2	1	**142**

Source: United States Patent and Trademark Office database

South Africa's share of patents at the USPTO is low and has generally been slowly declining (Table 5.4).

Table 5.4: South African patent grants at the USPTO

	TOTAL	SOUTH AFRICA (COUNT)	SOUTH AFRICA (%)
2015	**298 407**	166	0.056
2016	**303 051**	181	0.060
2017	**318 829**	182	0.057
2018	**307 760**	145	0.047
2019	**354 430**	182	0.051

Source: United States Patent and Trademark Office database

Table 5.5 ranks group of countries granted patents by the USPTO during 2019 (excluding the USA). Patent origin is determined by the residence of the first-named inventor listed on a patent. Japan is at the top of the list with 53 542 patents. South Korea follows with less than half the patents of the USA (21 684). China and Germany follow with 19 209 and 18 293 patents, respectively. South Africa is ranked 34th and is the lowest among the BRICS group of countries.

Table 5.5: Countries by number of foreign utility patents at the USPTO, 2019

	NUMBER OF FOREIGN UTILITY PATENTS	PERCENTAGE SHARE
BRICS	**25 816**	**13.78**
Low-income countries	**6**	**<0.01**
Burundi	1	<0.01
Eretria	1	<0.01
Lower middle-income countries	**5 760**	**3.08**
India	5 378	2.87
Iran	86	0.05
Egypt	34	0.02
Upper middle-income countries	**21 926**	**11.71**
China	19 209	10.25
Russia	622	0.33
Brazil	425	0.23
South Africa	182	0.10
High-income countries	**159 623**	**85.22**
Japan	53 542	28.58
South Korea	21 684	11.58
Germany	18 293	9.77
Total utility patents from outside the USA	**187 315**	**100.00**

Source: United States Patent and Trademark Office database

Table 5.6 shows the countries that were granted plant patents by the USPTO ranked according to the number of patents granted during 2019. At the top of the list is The Netherlands with 314 patents. Germany and Japan follow with 88 and 47 patents, respectively.

The table shows that only 25 countries were granted plant patents by the USPTO during 2019. In contrast, 126 countries were granted at least one utility patent. South Africa shares the 13th position together with China (10 patents each).

Table 5.6: Ranking of countries by the number of plant patents, 2019

1.	The Netherlands	314
2.	Germany	88
3.	Japan	47
4.	United Kingdom	46
5.	Denmark	37
6.	France	35
7.	Australia	31
8.	Belgium	30
9.	Israel	21
10.	Italy	18
11.	Thailand	15
12.	Canada	11
13.	South Africa	10
14.	China	10
15.	New Zealand	9
16.	Czech Republic	7
17.	Spain	5
18.	South Korea	4
19.	India	3
20.	Costa Rica	2
21.	Argentina	2
22.	Mexico	2
23.	Ireland	1
24.	Brazil	1
25.	Poland	1

Source: United States Patent and Trademark Office database

Table 5.7 shows the number of patents granted to South African inventors according to field of technology by the USPTO during the period 2011–2019. The most prolific fields of technology are medical technology with 123 patents and civil engineering with 116 patents during the period. The weakest fields are optics with eight patents during the period, and analysis of biological materials with 10 patents. It should be emphasised that the world emphasis in the USPTO is on electrical engineering (30%). The emphasis in the USA is also on electrical engineering disciplines (>50%) such as electrical machinery, audio-visual technologies, telecommunications, basic communication processes and semiconductors[7]. South Africa's emphasis on electrical engineering is just above 7%.

Table 5.7: Patents granted to South Africans by USPTO by field of technology

FIELD OF TECHNOLOGY	2011	2012	2013	2014	2015	2016	2017	2018	2019	TOTAL
Electrical machinery, apparatus, energy	5	4	5	1	3	6	5	4	7	74
Audio-visual technology	1	1	2	0	2	3	3	3	3	25
Telecommunications	1	2	1	5	2	3	4	2	3	34
Digital communication	3	3	2	6	3	1	4	4	3	34
Basic communication processes	1	3	1	1	2	1	1	1	1	14
Computer technology	6	7	10	11	11	8	4	4	4	79
IT methods for management	6	10	4	5	5	2	1	2	4	42
Semiconductors	2	0	2	4	2	3	2	0	1	18
Optics	0	0	0	0	2	0	1	3	1	8
Measurement	1	3	5	6	2	6	7	5	5	53
Analysis of biological materials	0	0	0	0	1	1	1	2	2	10
Control	1	3	6	5	2	1	1	3	3	38
Medical technology	10	12	10	12	11	11	8	8	11	123
Organic fine chemistry	8	6	14	4	8	9	5	2	1	81
Biotechnology	2	2	3	2	7	6	3	2	8	41
Pharmaceuticals	4	5	9	4	6	5	4	7	7	57
Macromolecular chemistry, polymers	2	1	2	0	1	1	0	1	1	14
Food chemistry	1	2	2	0	1	3	2	2	1	20
Basic materials chemistry	8	13	10	10	8	3	7	7	6	93
Materials, metallurgy	6	5	8	6	7	5	4	2	5	82
Surface technology, coating	1	4	3	2	1	3	4	0	0	23
Chemical engineering	8	8	8	6	8	7	2	4	3	91
Environmental technology	2	1	2	2	2	2	1	1	3	29
Handling	5	7	4	4	5	3	5	3	5	61
Machine tools	5	7	6	5	3	3	2	1	3	51
Engines, pumps, turbines	3	2	3	4	4	3	3	2	3	37
Textile and paper machines	1	2	2	2	2	1	1	0	1	14
Other special machines	6	8	4	7	10	7	8	4	6	87
Thermal processes and apparatus	3	0	2	1	1	3	3	6	3	28
Mechanical elements	2	1	7	4	3	4	4	2	1	52
Transport	2	3	4	4	3	6	8	7	3	71
Furniture, games	4	10	3	11	4	4	3	1	3	66
Consumer goods	2	1	4	4	4	2	0	4	3	33
Civil engineering	14	9	8	12	9	7	10	5	10	116
Total	**126**	**145**	**156**	**150**	**145**	**133**	**121**	**104**	**124**	**1 699**

Source: United States Patent and Trademark Office database

7 National Science Foundation, 2020. *The state of US science and engineering 2020*. National Science Foundation

Table 5.8 shows the main recipients of utility patents granted to South African organisations during 2011–2018. What stands out in trends is, of course, Amazon and a few new players.

Table 5.8: Main South African recipients of USPTO utility patents

	2010–2012	2013–2015	2016–2018
Amazon	5	26	70
Sasol	24	30	20
CSIR	10	17	15
Element Six	1	13	17
University of the Witwatersrand	7	16	9
University of Cape Town	6	11	12
Stellenbosch University	1	5	22
Detnet South Africa	2	8	14
Spinalmotion	10	12	0
Joy MM Delaware	2	10	4
North-West University	6	7	5
Simplify Medical	0	0	16
Cork Group Trading	5	9	1
Insiava	0	8	4
Oracle International Corporation	0	10	2
Visa International Service Association	0	0	11
Azoteq	7	3	4
Discovery Holdings	8	3	0
South African Nuclear Energy Corporation	3	5	2

Source: United States Patent and Trademark Office database

Table 5.9: South African patent grants at the European Patents Office

	NUMBER OF PATENT GRANTS
2010	53
2011	53
2012	65
2013	54
2014	50
2015	59
2016	70
2017	50
2018	73
2019	69

Source: European Patent Office database

The number of South African patents granted at the European Patents Office has fluctuated, but was marginally lower in 2019 than in 2016 (Table 5.9).

Patent applications at the Patent Cooperation Treaty (PCT) over the last three years have been dominated by the universities, with the University of Cape Town and Stellenbosch University being the most prominent (Table 5.10).

Table 5.10: PCT top applicants

	2017	2018	2019
University of Cape Town	10	11	18
Stellenbosch University	10	2	17
CSIR	7	8	9
University of Pretoria	8	4	5
NCM Innovations (Pty) Ltd	8	13	4
University of the Witwatersrand	10	4	4
Mmapro IT Solutions (Pty) Ltd	0	0	3
University of Johannesburg	0	1	3
AEL Mining Services Limited	0	0	2
Allbro (Pty) Ltd	0	0	2

Source: Centre for Research on Evaluation, Science and Technology, Stellenbosch University

Table 5.11: Domestic patent grants

	RESIDENT	NON-RESIDENT
2010	822	4 509
2011	567	4 729
2012	685	5 520
2013	474	4 282
2014	445	4 620
2015	453	4 046
2016	403	3 852
2017	595	4 940
2018	451	4 295
2019	694	5 468

Source: World Intellectual Property Organisation statistical country profiles

With respect to domestic patents, patents granted to South African residents increased from 451 in 2018 to 694 in 2019 – an increase of 53% (Table 5.11). However, there has been a downward trend since 2010. Patents granted to non-residents also rose significantly from 4 295 in 2018 to 5 468 in 2019 – an increase of 27%. Non-resident patent grants have fluctuated but, in contrast to patents granted to South African residents, were higher in 2019 than in 2010.

6. INNOVATION IMPACTS

Innovation has been demonstrated to be a significant driver of economic competitiveness and growth. On the other hand, it should have a meaningful impact on society in terms of social progress and wellbeing. The economic impact of innovation is discussed in this chapter, followed by the social impact of innovation.

6.1 Innovation for economic impact

The proxy indicators used in this section for economic impact are technology balance of payments, gross value added, outputs and exports.

6.1.1 Technology balance of payments

Table 6.1: Charges for the use of intellectual property

	PAYMENTS	RECEIPTS
	(CURRENT USD' 000)	
2010	1 941 103	113 985
2011	2 117 899	134 505
2012	2 017 094	124 888
2013	1 936 792	119 975
2014	1 731 992	116 469
2015	1 708 386	103 118
2016	1 984 245	109 422
2017	2 124 316	119 240
2018	1 817 432	120 716
2019	1 649 467	108 148

Source: World Bank's World Development Indicators

South Africa's payments abroad for the use of IP have declined by 22% since 2017 (see Table 6.1). Receipts from the sale of South African IP declined by 10% from the previous year. Receipts from the sale of IP have tended to decline and, in 2019, were lower than they were in 2010.

As Table 6.2 shows, Brazil, Argentina and South Africa have seen recent declines in their receipts from the sale of their IP abroad. But, for both Brazil and Argentina, in contrast to South Africa, receipts in 2019 were significantly higher than in 2015. Compared with all middle-income countries, South Africa's share of receipts declined significantly from 2.5% in 2015 to 1.0% in 2019.

Table 6.2: Charges for the use of IP receipts, South Africa and selected countries

	2015	2016	2017	2018	2019
	CURRENT USD				
Brazil	581 080 500	650 833 689	642 157 301	825 475 487	641 114 074
Argentina	161 745 947	168 807 424	356 498 296	329 887 115	272 364 615
South Africa	103 118206	109 423 730	119 040 051	120 715 706	108 148 202
Middle income ($000)	4 052 479	4 093 071	8 552 136	9 869 658	10 725 430
South Africa share of middle income	2.5%	2.6%	1.4%	1.2%	1.0%

Source: World Bank's World Development Indicators

6.1.2 Gross value added by sector

Manufacturing output has risen consistently, but slowly over the last decade. Gross value added (GVA) in 2019 was some 15% higher than in 2009 (Table 6.3). There was a marginal fall in manufacturing GVA in 2019. High- and medium-technology manufacturing increased output marginally in 2019, but its overall rate of growth over the decade was similar to that of the manufacturing sector as a whole. The share of high- and medium-technology manufacturing in total manufacturing was marginally lower in 2019 (29.36%) than in 2009. If motor vehicles are excluded, the share of high- and medium-technology was lower in 2019 (24.75%) compared to 2009 (26.52%).

Table 6.3: Manufacturing, medium- and high-technology manufacturing output (GVA)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	OUTPUT IN R' BILLION (CONSTANT 2010 PRICES)										
Manufacturing	339	359	370	377	381	382	381	384	383	387	384
Medium- and high-technology	101	106	108	107	108	108	111	113	112	108	113
Medium- and high-technology, excluding motor vehicles	90	93	94	94	94	93	95	97	96	92	95
PERCENTAGE SHARE OF MANUFACTURING OUTPUT											
Medium- and high-technology	29.95	29.59	29.09	28.45	28.29	28.35	29.16	29.51	29.22	27.99	29.36
Medium- and high-technology, excluding motor vehicles	26.52	26	25.51	24.82	24.55	24.41	25	25.33	24.95	23.89	24.75

Sources: Quantec and Statistics South Africa

With regard to the different sectors within high- and medium-technology manufacturing, percentage shares have generally been stable over the last decade (see Table 6.4). The only exceptions to this are special-purpose machinery, which has increased its share of output from 8.49% (2009) to 12.9% (2019), and motor vehicles, which has increased its share of output from 11.69% (2009) to 16.12% (2019).

Table 6.4: Medium- and high-technology sectors' output

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	PERCENTAGE SHARE										
Basic chemicals	17.63	16.31	16.23	14.78	15.08	15.80	16.61	15.36	14.71	14.84	14.06
Other chemical products	24.83	24.45	24.42	24.07	23.11	21.89	22.24	21.77	21.83	22.11	22.04
General-purpose machinery	8.80	9.29	9.17	10.85	10.37	10.18	9.61	9.41	9.17	8.96	9.33
Special-purpose machinery	8.49	9.12	9.18	10.90	11.69	12.23	12.46	12.06	12.17	11.92	12.19
Household appliances	0.80	0.89	0.83	0.97	0.96	1.04	1.03	0.99	0.89	0.91	0.95
Office, accounting, computing machinery	1.16	1.30	1.21	1.44	1.40	1.55	1.54	1.48	1.33	1.45	1.51
Electric motors, generators, transformers	1.12	1.20	1.40	1.22	1.28	1.36	1.36	1.42	1.27	1.28	1.14
Electricity distribution and control apparatus	2.01	1.67	1.63	1.21	1.20	1.08	1.06	1.00	1.19	1.16	1.12
Insulated wire and cables	1.17	1.19	1.15	0.84	0.81	0.77	0.73	0.72	0.83	0.83	0.80
Other electrical equipment	3.79	3.94	3.44	2.74	2.96	2.82	3.00	2.76	2.63	2.44	2.44
Radio, television and communication apparatus	2.79	2.86	3.14	3.18	3.30	3.66	3.17	3.21	3.23	2.97	2.90
Professional equipment	1.74	1.68	1.71	1.84	2.38	2.54	2.63	2.18	2.18	2.05	1.92
Motor vehicles	11.69	12.12	11.91	11.44	11.37	11.43	10.93	13.33	14.35	15.15	16.12
Parts and accessories	9.94	10.10	10.54	10.25	9.63	9.23	9.14	9.99	9.83	9.75	9.54
Other transport equipment	4.05	3.88	4.04	4.27	4.46	4.40	4.48	4.32	4.39	4.19	3.94

Sources: Quantec and Statistics South Africa

6.1.3 Merchandise exports by technological intensity

Since 2015, there has been a steady decline in the value of South African high-technology exports. By comparison with the previous year, the value of South Africa's high-technology exports declined by 10% in 2019.

As Table 6.5 shows, high-technology exports, as a share of manufactured exports, has also declined consistently since 2015, and declined further in 2019.

Table 6.5: South Africa and Brazil high-technology exports

	SOUTH AFRICA	BRAZIL	SOUTH AFRICA	BRAZIL
	VALUE (USD' MILLION)		PERCENTAGE SHARE OF MANUFACTURED EXPORTS	
2010	2 505 592	8 819 040	6.2%	12.3%
2011	2 763 367	9 155 405	6.2%	10.9%
2012	2 939 308	9 475 998	6.9%	11.5%
2013	2 717 238	9 070 091	6.8%	10.7%
2014	2 808 162	8 808 891	6.7%	11.7%
2015	2 934 141	9 447 829	7.7%	13.6%
2016	2 398 334	10 421 109	6.7%	14.8%
2017	2 198 489	10 756 517	5.7%	13.9%
2018	2 268 032	11 096 280	5.7%	13.4%
2019	2 043 756	9 427 925	5.5%	13.3%

Source: World Bank's World Development Indicators

As in South Africa, Brazil saw a decline in high-technology exports in 2019 compared to 2018 (see Table 6.6). However, in contrast to South Africa, over the decade 2010–2019, Brazil's exports of high-technology manufacture have tended to increase. Averaged over the three years between 2010 and 2012, South Africa's high-technology manufacture was 30% that of Brazil in the same period. Averaged over the three years between 2017 and 2019, South Africa's high-technology manufacture was 20% that of Brazil in the same period. In contrast to South Africa, in Brazil, the share of high-technology manufactured exports is higher than it was in 2010.

Table 6.6: Benchmarking of South African high-technology exports as a percentage of manufactured exports, 2019

COUNTRY	PERCENTAGE
Malaysia	51.8
China	30.8
World	23.6
Middle-income countries	22.6
Mexico	20.4
Brazil	13.3
Russian Federation	13.0
Chile	7.5
Portugal	6.9
South Africa	5.5
Argentina	5.2

Source: World Bank's World Development Indicators

High-technology exports as a share of manufactured exports is significantly lower in South Africa than the average for the world, for middle-income countries and for almost all other comparable countries.

Table 6.7: South African service exports

	SERVICE EXPORTS (CURRENT USD' MILLION)
2010	16 063
2011	17 346
2012	17 639
2013	16 815
2014	16 829
2015	15 050
2016	14 361
2017	15 773
2018	15 968
2019	14 727

Source: World Bank's World Development Indicators

As with high-technology manufactured exports, service exports have tended to be lower since 2012. Service exports declined sharply in 2019 – and were almost 8% lower than in 2018 (Table 6.7). Service exports were more than 16% lower in 2019 compared to 2012.

6.1.4 Medium- and high-technology employment

Employment in the formal manufacturing sector declined during 2009–2014 (see Table 6.8).

Table 6.8: Share of medium- and high-technology manufacturing employment

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Manufacturing employment ('000)	1 211	1 177	1 168	1 167	1 168	1 161	1 174	1 188	1 200	1 221	1 220
Medium- and high-technology employment ('000)	346	339	348	353	360	355	354	365	370	383	394
Percentage share of medium- and high-technology employment	28.55	28.78	29.79	30.30	30.79	30.60	30.17	30.68	30.74	31.36	32.31
Medium- and high-technology employment, excluding motor vehicles ('000)	305	298	306	310	316	312	310	318	320	335	347
Percentage share of medium- and high-technology employment, excluding motor vehicles	25.13	25.32	26.24	26.59	27.02	26.85	26.43	26.75	26.70	27.41	28.42

Sources: Quantec and Statistics South Africa

During 2014–18, employment grew slowly. Employment fell marginally in 2019 compared to 2018. In contrast to overall manufacturing, employment in high- and medium-technology manufacturing has tended to increase over the decade, albeit very slowly. Employment increased some 3% in 2019. Over the decade 2009–2019, employment in high- and medium-technology manufacturing has increased by a little over 48 000. The share of overall manufacturing employment rose from 28.5% (2009) to 32.31% (2019). Excluding motor vehicles does not alter the trend – high- and medium-technology manufacturing's share of overall manufacturing employment has been growing, albeit at a slow rate.

With regard to the different sectors within high- and medium-technology manufacturing, percentage shares of employment have been stable over the last decade. As shown in Table 6.9, the two sectors that had growing shares of output (special purpose machinery and motor vehicles) exhibit no change in their share of employment over the period.

Table 6.9: Medium- and high-technology sectors' employment

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	SHARE OF MANUFACTURING EMPLOYMENT (PERCENTAGE)										
Basic chemicals	5.98	6.34	6.86	7.42	7.50	6.98	6.39	5.93	6.09	6.19	6.00
Other chemical products	14.08	14.49	14.60	14.82	15.37	15.39	16.02	15.97	16.63	17.67	17.78
General-purpose machinery	12.71	12.75	12.58	12.71	12.80	12.54	11.89	11.83	12.19	12.43	12.52
Special-purpose machinery	16.26	15.68	15.30	14.82	14.81	15.26	15.27	14.96	15.73	16.24	16.21
Household appliances	2.04	1.98	1.91	1.91	1.90	2.08	2.00	2.02	1.99	1.75	1.47
Office, accounting, computing machinery	1.88	1.83	1.64	1.57	1.44	1.24	1.15	1.22	1.23	1.18	1.06
Electric motors, generators, transformers	2.15	2.73	3.72	3.60	3.97	4.48	4.49	4.38	3.95	4.04	3.95
Electricity distribution and control apparatus	2.01	1.62	1.74	1.78	1.54	1.61	1.87	1.85	1.89	1.84	1.76
Insulated wire and cables	1.54	1.54	1.50	1.55	1.51	1.47	1.45	1.42	1.35	1.23	1.11
Other electrical equipment	5.16	5.30	5.31	5.11	4.98	4.68	4.59	4.54	3.04	3.57	5.75
Radio, television and communication apparatus	1.93	1.89	1.81	1.73	1.82	1.95	1.92	1.94	1.92	1.82	1.68
Professional equipment	2.88	3.06	2.99	3.05	2.97	3.00	2.96	3.11	3.28	3.29	3.23
Motor vehicles	11.92	11.98	11.87	12.19	12.19	12.19	12.33	12.75	13.09	12.53	11.99
Parts and accessories	14.73	14.03	13.74	13.57	13.23	13.00	13.40	13.55	13.09	11.87	11.08
Other transport equipment	4.73	4.77	4.42	4.19	3.97	4.13	4.28	4.55	4.53	4.38	4.42

Sources: Quantec and Statistics South Africa

6.2 Innovation for inclusiveness and social impact

This section performs an analysis of South Africa's social and human development performance through the use of the Social Progress Index and the Human Development Index. These indices combine standard of living and wellness indicators that resonate well with the NDP's developmental goals, such as access to water, food security, education and health.

6.2.1 Social Progress Index

The trend of South Africa's ranking on the SPI, shown in Figure 6.1, depicts two distinct periods, an improvement phase (2011–2016) and a recent deterioration phase (2017–2020). The best ranking was in 2016 (75^{th}) and the lowest ranking was in 2020 (86^{th}).

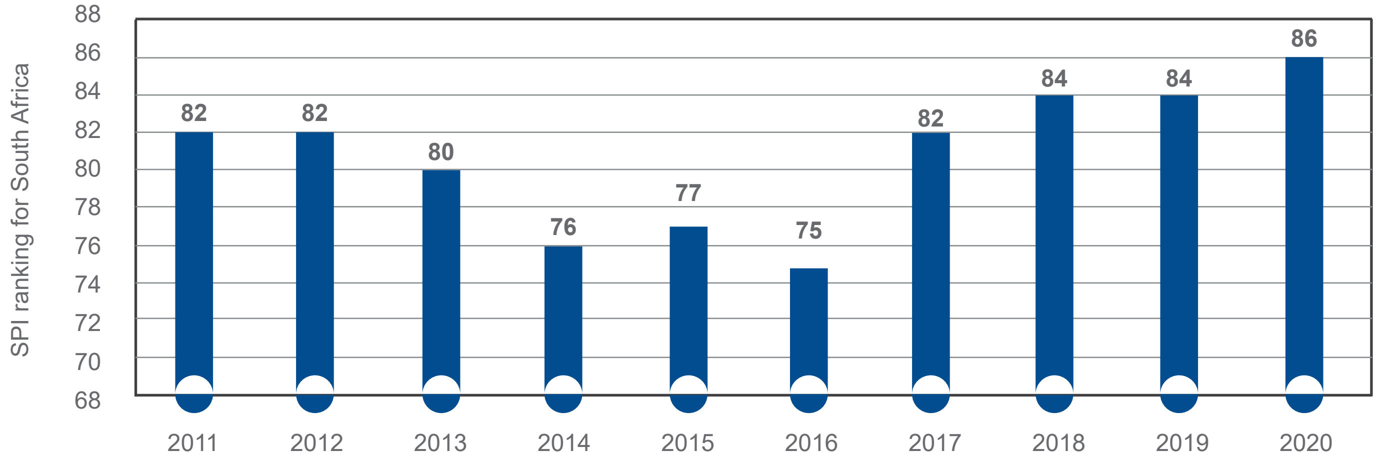


Figure 6.1: Trend of South Africa's Social Progress Index ranking
Source: Social Progress Index data

This low ranking of South Africa in 2020 is still competitive relative to its neighbours and an average (equivalent ranking) of the rest of Africa (Table 6.10). A notable exception is Tunisia, which ranked 55th, boosted mainly by strong Opportunity (47th) and Basic Human Needs (65th) pillars. However, among the members of BRICS, South Africa's SPI ranking is above that of China (100th) and India (117th). China's low SPI ranking shows an importance of non-economic indicators of progress. The same can be said about the relatively low SPI ranking for the high-income countries such as Singapore (29th) and the USA (28th).

It is observed that most Asian countries in this benchmark group of countries rank relatively low on Opportunity, except for India. On the contrary, several African countries (including South Africa) perform relatively better on this pillar.

Table 6.10: Social Progress Index rankings, 2020

	OVERALL SPI	BASIC HUMAN NEEDS	FOUNDATIONS OF WELLBEING	OPPORTUNITY
	RANKING OUT OF 163 COUNTRIES			
World	**93**	**104**	**131**	**123**
Africa	**131**	**133**	**131**	**123**
South Africa	82	106	89	48
Botswana	86	108	70	62
Egypt	112	96	148	116
Eswatini	131	123	128	145
Lesotho	127	153	120	81
Mozambique	142	150	132	132
Namibia	95	112	85	59
Nigeria	136	144	130	125
Tunisia	55	65	82	47
Zimbabwe	132	143	110	142
BRICS	**93**	**100**	**100**	**74**
Brazil	61	82	58	61
China	100	80	105	108
India	117	114	150	94
Russia	69	72	71	70
Upper middle income	**78**	**85**	**75**	**76**
Malaysia	48	47	43	64
Other select countries				
Singapore	29	3	28	38
South Korea	17	7	17	22
United Kingdom	20	24	16	18
United States	28	34	36	14

Source: Computed by NACI from the 2020 Social Progress Index report

A detailed breakdown of the SPI components is shown in Table 6.11. In general, most countries rank high on inclusiveness (equivalent ranking of 82nd), followed by health and wellness (83rd), personal safety (87th), access to advanced education (87th) and personal freedom and choice (88th). Among the BRICS member countries, a relative strength on SPI components is access to advanced education (48th), whereas environmental quality is a major challenge (151st). Several long-term investors are shifting their investment to the companies that are responsible with regard to strategies that do not harm the environment. Mozambique is one of the countries that is excelling with regard to environmental quality.

The main social challenges in Africa are nutrition and basic medical care (equivalent ranking of 134th), shelter (134th), water and sanitation (133rd), access to basic knowledge (132nd) and access to information and communication (131st). For South Africa, the two main challenges are personal safety (142nd) and environmental quality (126th). The indicators used for personal safety in constructing the SPI rankings are homicide rate, perceived criminality, political killings and torture, and traffic deaths. COVID-19 lockdown restrictions have exposed alcohol abuse as one of the main contributors of non-natural deaths and traffic accident-related deaths.

Table 6.11: Ranking for components of the Social Progress Index

	BASIC HUMAN NEEDS				FOUNDATIONS OF WELLBEING				OPPORTUNITY			
	NUTRITION AND BASIC MEDICAL CARE	WATER AND SANITATION	SHELTER	PERSONAL SAFETY	ACCESS TO BASIC KNOWLEDGE	ACCESS TO INFORMATION AND COMMUNICATIONS	HEALTH AND WELLNESS	ENVIRONMENTAL QUALITY	PERSONAL RIGHTS	PERSONAL FREEDOM AND CHOICE	INCLUSIVENESS	ACCESS TO ADVANCED EDUCATION
World	**101**	**103**	**106**	**87**	**99**	**95**	**83**	**90**	**93**	**88**	**82**	**87**
Africa	**134**	**133**	**134**	**122**	**132**	**131**	**129**	**105**	**114**	**130**	**104**	**124**
South Africa	104	101	86	142	85	72	99	126	56	42	46	75
Botswana	119	111	109	60	65	96	86	58	54	41	84	104
Egypt	89	69	99	130	108	111	139	162	143	75	137	62
Eswatini	123	128	112	132	120	120	149	105	156	78	131	121
Lesotho	160	150	139	153	99	114	146	137	81	72	48	131
Mozambique	150	146	149	127	139	144	150	26	103	156	64	154
Namibia	112	115	113	89	96	85	105	62	49	45	66	106
Nigeria	146	134	132	157	138	107	116	142	75	151	150	102
Tunisia	58	70	61	94	103	54	59	140	48	47	47	71
Zimbabwe	126	126	132	158	89	124	151	51	135	119	141	118
BRICS	**96**	**92**	**93**	**124**	**87**	**74**	**92**	**151**	**114**	**70**	**104**	**48**
Brazil	65	68	37	137	88	49	77	63	80	71	85	56
China	46	75	98	96	73	79	76	160	155	52	140	34
India	117	119	110	105	129	99	124	163	94	112	119	83
Russia	51	63	58	128	34	66	83	132	131	58	116	13
Upper middle income	**89**	**83**	**85**	**94**	**75**	**85**	**80**	**98**	**99**	**83**	**95**	**74**
Malaysia	83	52	60	43	33	32	74	85	91	60	102	50
Other select countries												
Singapore	24	24	27	2	41	35	3	81	89	11	45	29
South Korea	19	25	30	5	26	1	5	68	24	27	38	3
United Kingdom	21	1	19	27	42	3	23	22	22	17	30	16
United States	29	23	16	56	43	11	41	100	35	19	34	1

Source: Computed by NACI from 2020 Social Progress Index report

6.3.1 Human Development Index

The HDI ranking trend for South Africa (Figure 6.2) shows a pattern similar to that of the SPI. The two periods of improvement and deterioration in human development within the country are also very clear. The main difference is that the HDI is reported for the preceding year. The highest level of development over the last decade was therefore in 2015, in which South Africa was ranked 108th.

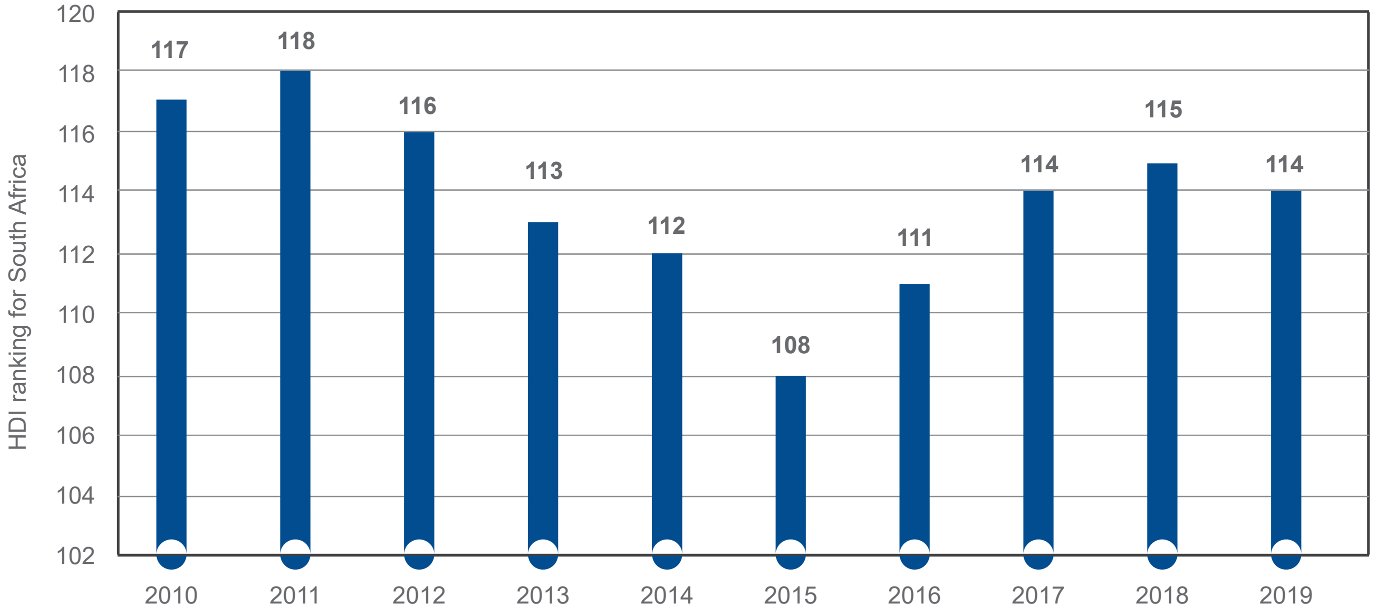


Figure 6.2: Trend of South African Human Development Index ranking
Source: United Nations Development Programme's Human Development Index data

The rankings on various components of the HDI for South Africa and other benchmark countries or groups of countries in 2019 are shown in Table 6.12. As shown, South Africa's low HDI ranking is mainly influenced by a low life expectancy at birth (64.1 years in 2019). The COVID-19 pandemic is likely to worsen the situation in 2020 and 2021. Most of South Africa's neighbours also have this challenge of low life expectancy at birth, the worst being Lesotho (187th out of 189 countries), followed by Eswatini (178th), Mozambique (176th) and Zimbabwe (173rd). Although the equivalent ranking of the African continent on life expectancy at birth is 157th, Tunisia shows a better ranking of 63rd with a value of 76.7 years in 2019. Among the BRICS member countries, China and Brazil rank high on life expectancy at birth (59th and 72nd, respectively).

In terms the income, South Africa performs better than most of the countries on the African continent (100th), although Botswana is performing much better (73rd). The gross national income per capita of Mozambique (18th) is the lowest among South Africa's neighbours.

Even though South Africa's mean years of schooling (10.2 years) is lower than the expected years of schooling (13.8 years), its ranking on mean years of schooling is higher (74th). Therefore, South African students have more opportunities for tertiary education, as confirmed by the SPI rankings. On the contrary, most of the Asian countries in this benchmark group of countries (except Malaysia) are ranked high on expected years of schooling. This shows a higher emphasis on knowledge application than the pursuit of high-end skills. Brazil and Tunisia also rank very high on expected years of schooling (43rd and 51st, respectively) in comparison to mean years of schooling (116th and 126th, respectively).

Table 6.12: Human Development Index rankings, 2019

	OVERALL HDI	LIFE EXPECTANCY AT BIRTH	EXPECTED YEARS OF SCHOOLING	MEAN YEARS OF SCHOOLING	GROSS NATIONAL INCOME PER CAPITA
	RANKING OUT OF 189 COUNTRIES				
World	**106**	**103**	**94**	**102**	**64**
Africa	**153**	**157**	**156**	**151**	**132**
South Africa	114	160	85	74	100
Botswana	100	134	109	86	73
Egypt	116	115	93	120	102
Eswatini	138	178	129	131	119
Lesotho	165	187	145	139	159
Mozambique	181	176	165	180	184
Namibia	130	165	119	129	113
Nigeria	161	185	165	135	142
Tunisia	95	63	51	126	109
Zimbabwe	150	173	154	105	164
BRICS	**94**	**116**	**81**	**97**	**78**
Brazil	84	72	43	116	85
China	85	59	83	112	74
India	131	133	124	139	126
Russia	52	109	54	31	54
Upper middle income	**90**	**87**	**86**	**90**	**73**
Malaysia	62	68	88	67	51
Other select countries					
Singapore	11	4	25	41	3
South Korea	23	8	23	31	27
United Kingdom	13	27	15	5	26
United States	17	37	28	2	10

Source: Computed by NACI from the United Nations Development Programme's 2020 Human Development Index data

7. SECTORAL AND PROVINCIAL SYSTEMS OF INNOVATION

This chapter analyses the sectoral and regional systems of innovation. Both these systems are the key levers for the implementation of socioeconomic policies and strategies.

7.1 Sectoral systems of innovation

The bio-economy sector was selected for analysis.

7.1.1 The bio-economy sector

The South African Bio-economy Strategy was approved in January 2014[8]. In order to avoid yearly fluctuations, the performance of the bio-economy sector since the adoption of the strategy is assessed against a base, a three-year average from 2013 to 2015.

There has been a significant increase in the number of biotechnology publications since the adoption of the Bio-economy Strategy. There was a particularly significant increase in publications in 2019 compared to 2018 (23%). Moreover, South Africa's global share of biotechnology publications also increased significantly.

Table 7.1: Biotechnology and applied microbiology publications in peer-reviewed journals*

	2008–2010 (AVERAGE)	2013–2015 (AVERAGE)	2016	2017	2018	2019
Total number of South African (co-) authored publications	176	167	187	191	183	226
Share of South African (co-) authored publications	0.83%	0.64%	0.75%	0.73%	0.74%	0.88%

Source: Centre for Research on Evaluation, Science and Technology, Stellenbosch University

*Note: Data extracted from the Centre for Science and Technology Studies (CWTS)'s in-house version of the Web of Science database.

Table 7.2: Biotechnology patents granted at the USPTO

	NUMBER OF BIOTECHNOLOGY PATENTS
2010	2
2011	2
2012	2
2013	3
2014	2
2015	7
2016	6
2017	3
2018	2
2019	8
Base: 2013–2015	6

Source: USPTO database

There was also a very significant increase in South African biotechnology patents granted at the USPTO in 2019. However, as Table 7.2 shows, the increase in patents in 2019 is from a very low base. It is a one-year increase and it follows a tendency to decline after the adoption of the Bio-economy Strategy. Patents in 2019 are higher than the per annum average for the period 2013–2015. However, overall, the yearly average number of patents granted between 2016 and 2019 are lower (five) than the yearly average number of patents granted in the base years, between 2013 and 2015 (six).

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

Table 7.3: Bio-economy GDP output and share of total South African GDP

	BIO-ECONOMY GDP OUTPUT (R' MILLION AT CONSTANT 2010 PRICES)	BIO-ECONOMY'S SHARE OF TOTAL GDP
2010	211 779	8.49%
2011	217 221	8.44%
2012	239 906	8.51%
2013	227 324	8.42%
2014	235 296	8.55%
2015	232 134	8.34%
2016	227 800	8.14%
2017	240 772	8.48%
2018	242 285	8.47%
2019	230 738	8.05%
Base: 2013–2015	231 585	8.44%

Source: Quantec and Statistics South Africa

The Bio-economy Strategy has three key economic objectives: increase the contribution of the bio-economy to GDP through high growth, create more employment and make the country more competitive.

As Table 7.3 shows, there was a significant decline in the output of the bio-economy in 2019 compared with 2018 (-4.8%). Output in 2019 is marginally lower than the per annum average for the years 2013 to 2015. There has been a tendency for the share of the bio-economy output in total South African output to decline. In 2019, the share of the bio-economy in total South African output (8.05) was lower than the yearly average for the period 2013–2015 (8.44%)

Table 7.4: Bio-economy sector employment+

	BIO-ECONOMY EMPLOYMENT	PERCENTAGE OF TOTAL SOUTH AFRICAN EMPLOYMENT
2010	1 367 597	9.6%
2011	1 326 818	9.2%
2012	1 387 154	9.3%
2013	1 476 467	9.7%
2014	1 435 196	9.3%
2015	1 684 443	10.6%
2016	1 647 170	10.4%
2017	1 618 197	10.0%
2018	1 606 563	9.8%
2019	1 599 869	9.8%
Base: 2013–2015	1 532 036	9.9%

Source: Quantec and Statistics South Africa

+Note: Total employment = Formal and informal employment

As Table 7.4 shows, in 2019, there was a similar decline in employment as an output in the bio-economy. Employment in the bio-economy in 2019 declined by 4.2% in 2019 compared with 2018. The share of the bio-economy in total South African employment in 2019 (9.8%) was marginally lower than the yearly average for the period 2013–2015 (9.9%).

A key objective of the Bio-economy Strategy was to increase exports and South Africa's competitiveness in global markets. In addition to increasing total bio-economy exports, South Africa's bio-economy exports would, as a result of enhanced technological change and innovation, be more sophisticated and hence of higher value.

Table 7.5: Bio-economy sector exports

	BIO-ECONOMY EXPORTS (CURRENT USD ' MILLIONS)	PERCENTAGE OF TOTAL SOUTH AFRICAN EXPORTS	UNIT VALUE US$
2010	17 124	9.6%	0.74
2011	19 823	9.2%	0.77
2012	20 149	9.3%	0.75
2013	20 052	9.7%	0.74
2014	20 288	9.3%	0.85
2015	17 970	10.6%	0.91
2016	16 592	10.4%	1.1
2017	19 149	10.0%	0.91
2018	20 499	9.8%	0.88
2019	19 578	9.8%	0.88
Base: 2013–15	19 436	9.9%	0.83

Source: Quantec and Statistics South Africa

In 2019, there was a small decline in exports compared to 2018 (0.7%). There has been no tendency for the bio-economy's share of total South African exports to increase. The bio-economy's share of total South African exports was marginally lower in 2019 (9.8%) than in the base years 2013–2015. More technologically advanced and innovative products would find a reflection in the higher unit value prices of exports. The situation in this regard is unclear. There was a notable increase in the unit value of South African bio-economy exports in 2016, but a decline thereafter. In 2019, the unit value of South Africa's bio-economy was the same as in 2018 ($0.88). The per annum average for the period 2013–2015 was $0.83.

In brief:

- The number of biotechnology publications increased significantly in 2019 compared to 2018. South Africa's share of biotechnology publications has been increasing.
- The number of bio-economy patents increased in 2019 compared with 2018. The share of South African bio-economy patents is similar to that in 2013–2015.
- Output, employment and exports in the bio-economy declined in 2019 compared with 2018. Bio-economy output, employment and exports, as a share of the total, have tended to decline since 2013–2015.
- This strong performance in terms of science (publications) and moderate performance in terms of technology (patents), contrasting with weak performance in the economic magnitudes (output, employment and exports) in the bio-economy, is mirrored in the performance of the business sector as a whole.

Note: The economic data for the bio-economy is for the core bio-economy as defined by the Department of Science and Innovation: SIC1; SIC30; SIC331; SIC3312; SIC333; SIC335; SIC336.

7.2 Regional systems of innovation

The role of regions in promoting innovation is gaining increasing significance. National policy makers have shown a growing interest in the regional dimension of innovation processes, and regional policy makers are seeking to promote their own competitiveness by supporting innovation. In terms of global competition, attention is increasingly being drawn to the regions as sources of competitiveness. In South Africa, the regional dimension was reinforced in the 2019 White Paper for Science, Technology and Innovation. This section is aimed at assessing the provincial regional dimension of STI.

7.2.1 Provincial economic structures and performance

In 2017, Gauteng generated just over a third of South Africa's GDP (38%), making it the largest provincial economy (Figure 7.1). KwaZulu-Natal was second (16%), followed by the Western Cape (14%). As shown in the figure, the provinces with the smallest economic output are the Northern Cape (2%), the Free State (5%) and North West (6%).

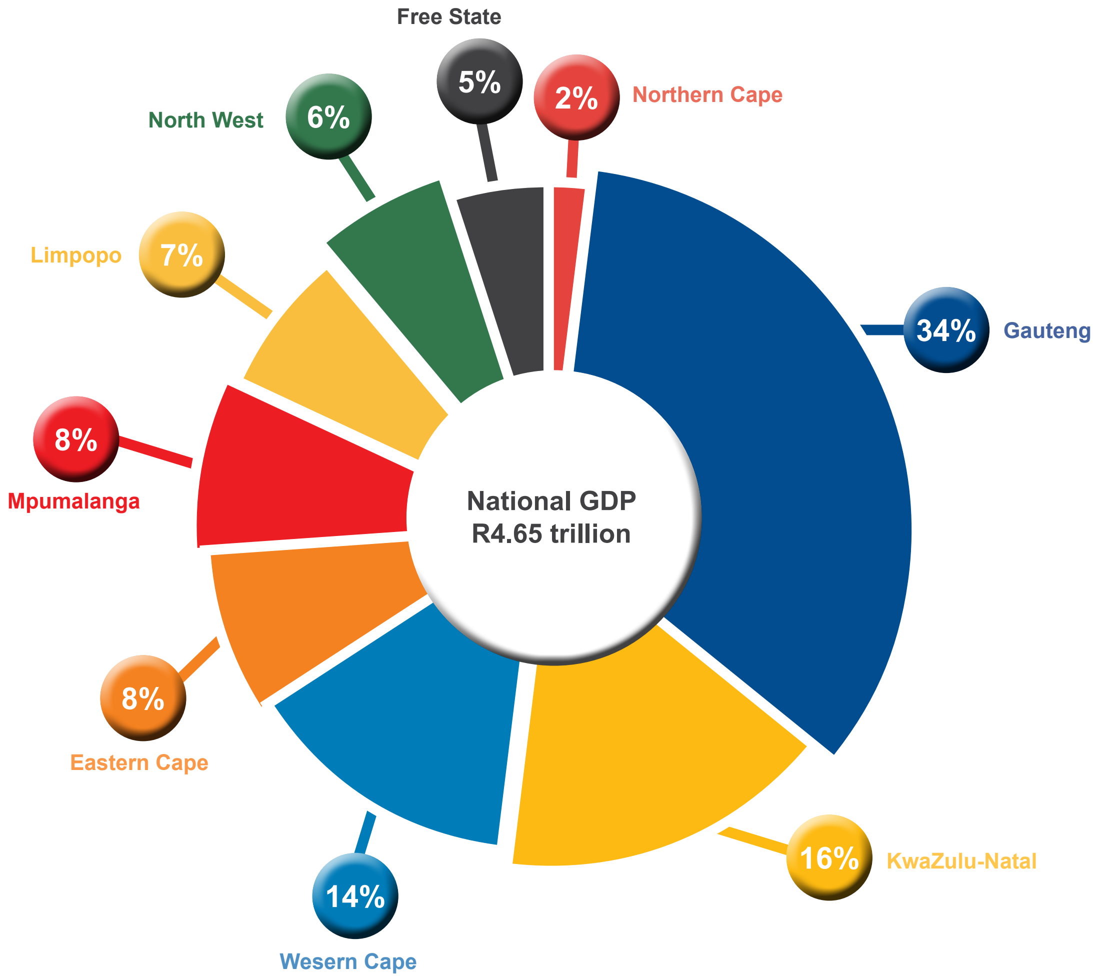


Figure 7.1: Sizes of provincial economies
Source: Statistics South Africa

As shown in Figure 7.2, Gauteng is also the top-ranking province in terms of GDP per capita, followed by the Western Cape and the Free State.

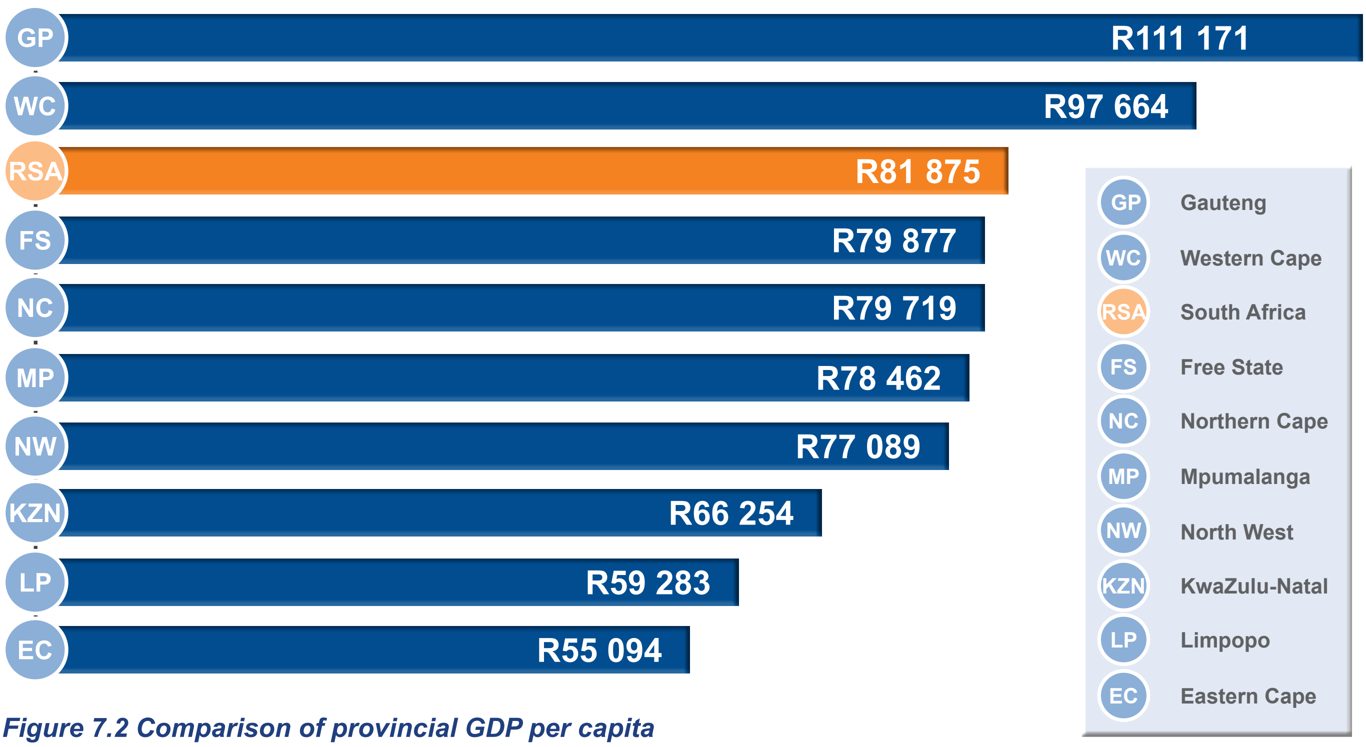


Figure 7.2 Comparison of provincial GDP per capita
Source: Statistics South Africa

The Eastern Cape, on the other hand, was the lowest ranking province. These findings show the disparities in the sizes of the provincial economies and GDP per capita. Gauteng's economic dominance is expected because finance, government, manufacturing, construction and four other industries are heavily represented in the province (Figure 7.3).

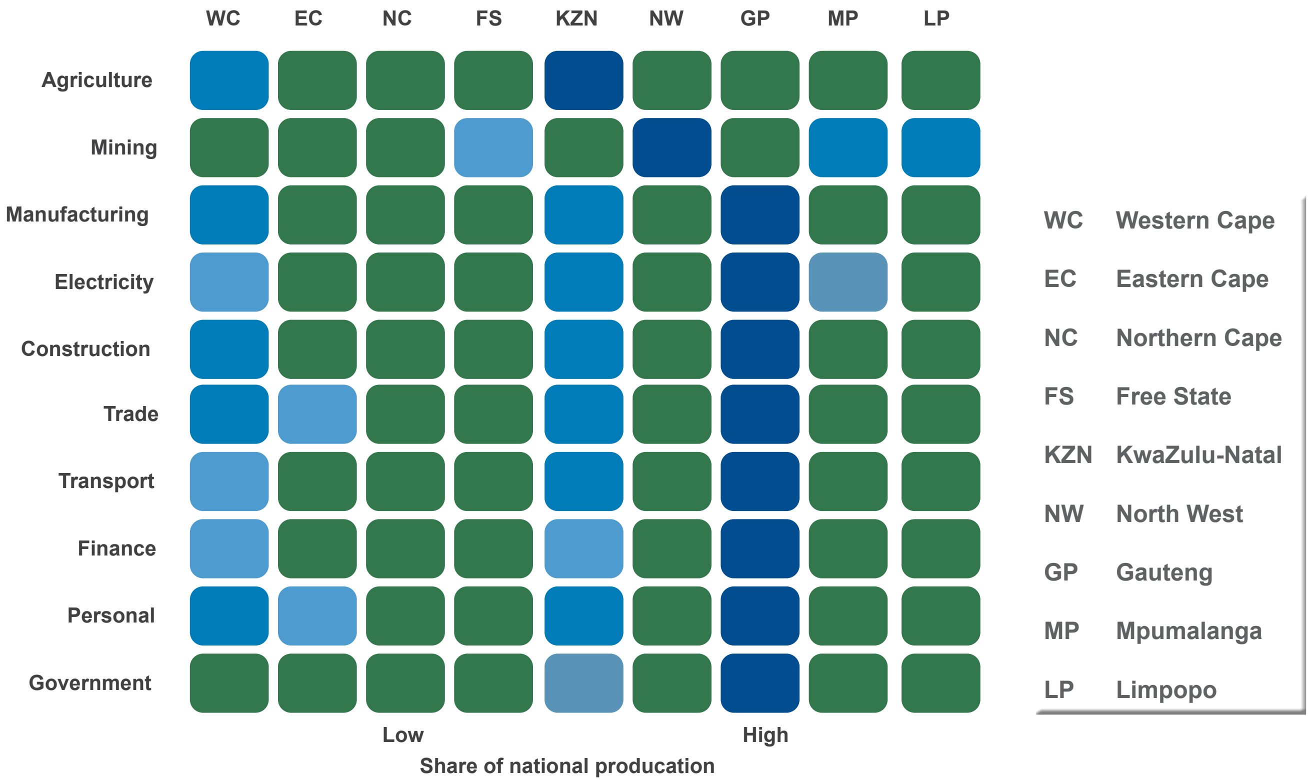


Figure 7.3: Distribution of economic activity across the country for each industry, 2017

Source: Statistics South Africa

National agriculture production is mostly concentrated in the Western Cape and KwaZulu-Natal. On the other hand, the bulk of national mining activity takes place in North West, Mpumalanga and Limpopo.

Table 7.6 shows the economic growth of the provinces from 2013 to 2017. Overall, the economic performance of all the provinces was very low. The Northern Cape's GDP expanded by 2.8%, the highest rate of all provinces. Mining was one of the contributors to the Northern Cape's strong growth in 2017. Agriculture was also a major contributor to the rise in economic growth.

Table 7.6: Comparison of provincial economic growth

PROVINCES	2013	2014	2015	2016	2017
	PERCENTAGE GROWTH				
Western Cape	2.3	1.9	1.5	1.1	1.2
Eastern Cape	1.1	0.9	0.7	0.8	0.6
Northern Cape	2.1	2.8	0.9	0.3	2.8
Free State	1.7	1.7	-0.2	-0.1	1.4
KwaZulu-Natal	2.1	2.1	0.8	0.7	1.8
North West	2.5	-3.8	4.9	-3.6	2
Gauteng	2.6	2.1	1.4	1.4	1.1
Mpumalanga	1.7	2.7	-0.2	0.2	1.9
Limpopo	2.4	0.8	1.9	-0.6	2.1
Total	**2.2**	**1.5**	**1.3**	**0.4**	**1.4**

Source: Business Insider (www.businessinsider.co.za)

7.2.2 Provincial R&D performance trends

Table 7.7 shows provincial R&D expenditure for the nine provinces. The data shows that, between 2014/15 and 2018/19, Gauteng enjoyed the highest R&D expenditure, followed by the Western Cape and KwaZulu-Natal. These provinces are the main industrial hubs in the country. The largest and leading universities in the country are located in these provinces. Moreover, science councils such as the CSIR, Agricultural Research Council (ARC), Mintek and others have their key research facilities in these provinces.

Table 7.7: Provincial R&D expenditure trends between 2014/15 and 2018/19

PROVINCES	2014/15	2015/16	2016/17	2017/18	2018/19
	R'000				
GERD	**29 344 977**	**32 336 679**	**35 692 973**	**38 724 590**	**36 783 968**
Eastern Cape	1 734 411	2 142 919	2 206 473	2 300 631	2 211 524
Free State	1 456 461	1 778 469	1 834 572	2 149 267	1 976 953
Gauteng	13 686 734	14 666 111	16 421 582	17 319 635	15 767 101
KwaZulu-Natal	3 187 481	3 335 141	3 639 100	4 172 713	4 074 154
Limpopo	628 607	627 125	728 874	854 885	806 624
Mpumalanga	859 201	791 248	699 720	715 616	853 859
Northern Cape	575 584	660 963	532 530	576 963	905 844
North West	1 402 742	1 209 434	1 298 778	1 306 478	1 682 406
Western Cape	5 813 758	7 125 269	8 331 345	9 328 402	8 505 504

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Figure 7.4 displays the trends of the proportional R&D expenditure. As the graph shows, although Gauteng has the highest proportional expenditure (42% in 2019), this has been in decline since 2016/17. The Western Cape, on the other hand, increased its proportion of R&D expenditure from 19.8% to 24.1% from 2014/15 to 2017/18, but this was followed by a decline to 23.1% in 2019. As the graph shows, none of the other provinces have increased their R&D expenditure significantly. The data shows significant disparities in R&D expenditure among the provinces. This has implications on innovation performance and designing regional innovation policies, which should be taken into consideration.

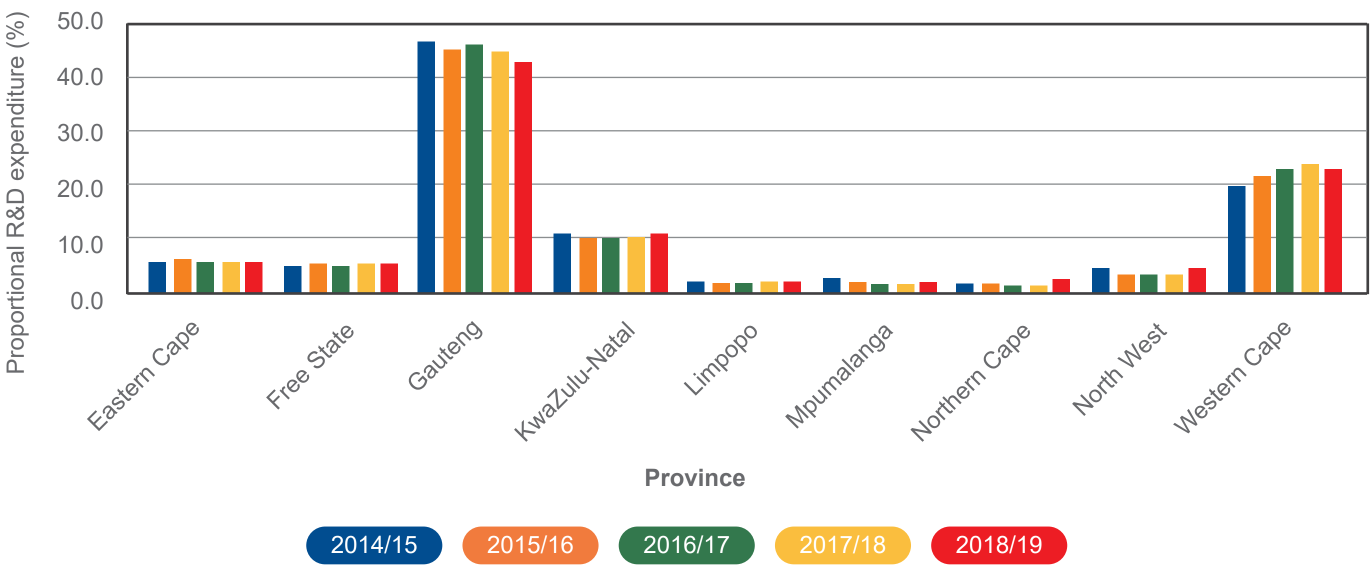


Figure 7.4: Provincial proportional R&D expenditure
Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Table 7.8 shows business expenditure on R&D for each province between 2014/15 and 2018/19. Businesses are central to innovation. The level of investment in R&D is important to generate new products, services and processes. The data shows that Gauteng has the largest expenditure, followed by the Western Cape and KwaZulu-Natal.

Table 7.8: Business sector R&D expenditure by province

PROVINCES	2014/15	2015/16	2016/17	2017/18	2018/19
	R'000				
Eastern Cape	608 398	651 533	690 478	707 348	674 516
Free State	831 575	1 124 042	1 060 177	1 105 873	991 206
Gauteng	7 160 280	7 183 557	7 876 139	8 285 425	7 617 873
KwaZulu-Natal	1 501 659	1 436 737	1 553 130	1 679 718	1 446 281
Limpopo	161 331	145 736	171 567	223 014	184 199
Mpumalanga	435 770	339 985	284 655	304 990	392 986
North West	681 634	451 891	526 962	565 486	601 653
Northern Cape	226 303	206 786	49 508	60 007	50 561
Western Cape	1 684 001	2 274 728	2 568 653	2 927 324	2 488 558
Total	**13 290 951**	**13 814 995**	**14 781 270**	**15 859 185**	**14 447 833**

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Figure 7.5 displays the proportional trend of business R&D expenditure. The trend shows that business expenditure in R&D in Gauteng has declined slightly since 2014/15 (from 53.9% to 52.7%). On the other hand, the proportional expenditure in the Western Cape increased from 16.5% in 2014/15 to 17.2% in 2019. KwaZulu-Natal has experienced a declined in proportional expenditure from 11.3% in 2014/15 to 10% in 2018/19. For the rest of the provinces, the proportion of R&D expenditure has not changed significantly except for the Northern Cape. This province has experienced a significant decline in BERD, from 1.7% in 2014/15 to 0.3% in 2018/19.

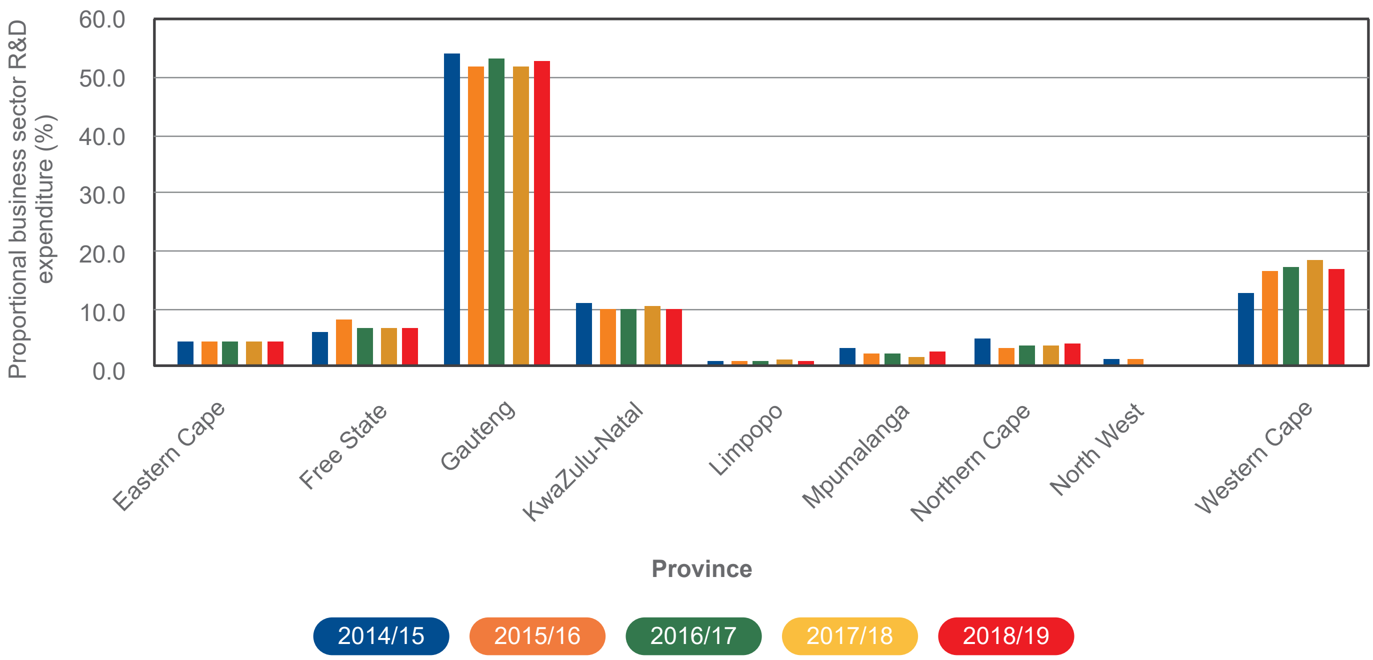


Figure 7.5: Proportional business sector R&D expenditure by province
Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

An important source of funding for research is government through its various programmes and funding instruments. Table 7.9 shows government expenditure for the provinces between 2014/15 and 2018/19. As the data shows, Gauteng again has the highest expenditure, followed by the Western Cape and the Eastern Cape, which is slightly higher than KwaZulu-Natal.

Table 7.9: Government-sector R&D expenditure by province

PROVINCE	2014/15	2015/16	2016/17	2017/18	2018/19
	R'000				
Eastern Cape	227 427	225 603	222 456	281 201	305 629
Free State	60 860	61 802	81 957	81 890	59 694
Gauteng	760 199	832 397	885 142	974 192	836 827
KwaZulu-Natal	177 517	187 088	172 655	206 551	236 602
Limpopo	83 683	84 232	76 541	86 876	89 889
Mpumalanga	93 566	112 173	107 237	104 154	88 922
North West	56 719	61 815	57 994	60 594	66 727
Northern Cape	52 579	69 174	66 200	94 659	88 575
Western Cape	380 461	378 737	428 465	435 757	450 560
Total	**1 893 010**	**2 013 021**	**2 098 646**	**2 325 875**	**2 223 426**

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Figure 7.6 shows that government's proportional R&D expenditure in Gauteng declined from 41% in 2014/15 to 37.6% in 2018/19. During the same period, the proportional expenditure in the Western Cape has essentially remained the same at 20.3%. As the graph shows, the Eastern Cape and KwaZulu-Natal have enjoyed modest proportional increases. The proportional expenditure in the Eastern Cape rose from 12% in 2014/15 to 13.6% in 2018/19. On the other hand, proportional expenditure in KwaZulu-Natal increased from 9.4% in 2014/15 to 10.6% in 2018/19. Despite these increases, businesses in these provinces spend far less on R&D than their counterparts in Gauteng and the Western Cape.

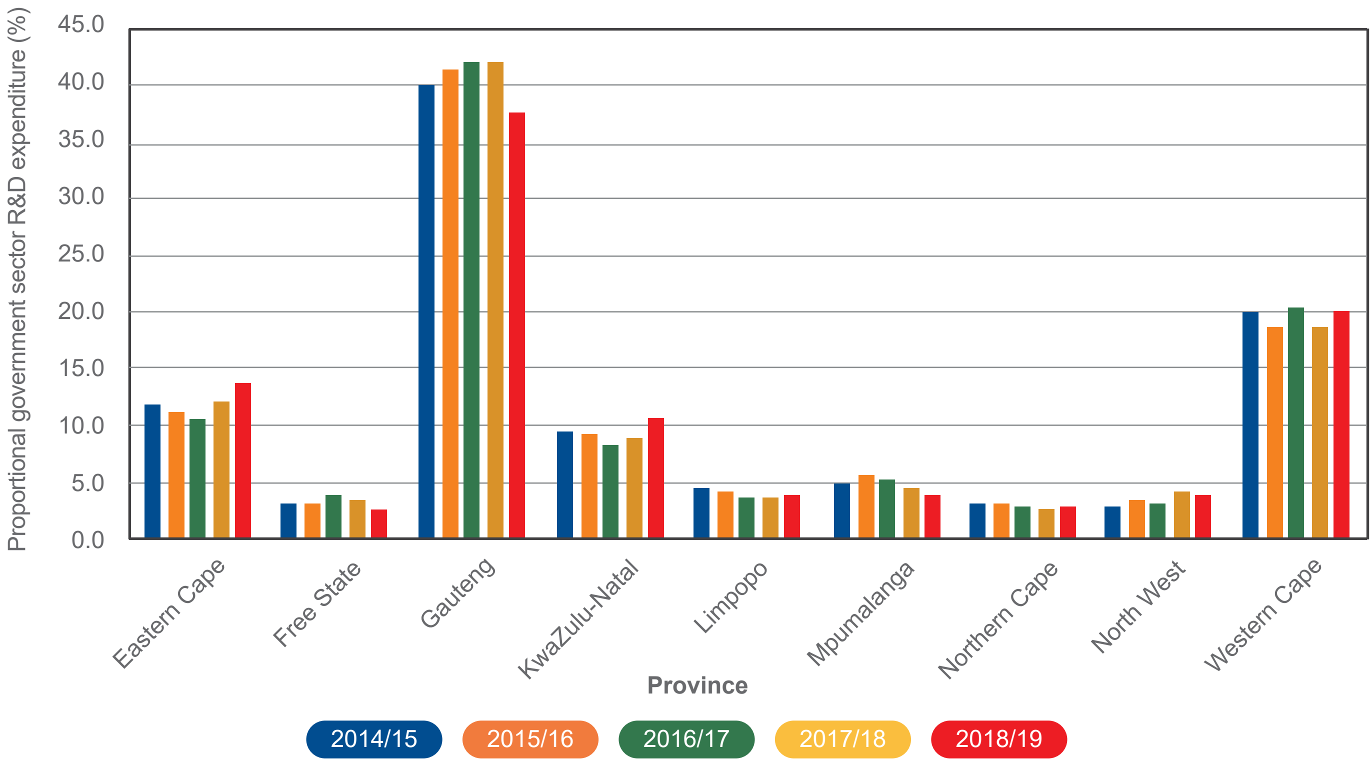


Figure 7.6: Proportional government R&D expenditure by province

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

Higher education institutions are key actors in the regional innovation system in stimulating innovation and economic development. The presence of universities who 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 R&D by the higher education sector in the provinces is displayed in Table 7.10.

The data in the table shows that Gauteng and the Western Cape were the leaders in higher education R&D expenditure during the period under review. In 2018/19, the Western Cape had the highest expenditure (R4.4 billion), followed by Gauteng (R3.7 billion) and KwaZulu-Natal (R1.6 billion).

Table 7.10: Higher education sector R&D expenditure by province

PROVINCE	2014/15	2015/16	2016/17	2017/18	2018/19
	R'000				
Eastern Cape	612 239	975 099	1 002 978	1 017 383	1 027 996
Free State	491 203	523 782	625 646	894 118	803 727
Gauteng	2 733 330	3 305 576	4 105 237	4 269 020	3 730 236
KwaZulu-Natal	843 111	903 664	1 157 722	1 428 653	1 646 915
Limpopo	216 352	229 364	301 809	358 543	384 346
Mpumalanga	174 657	190 716	148 981	155 430	170 553
North West	404 575	444 135	469 171	449 196	833 635
Northern Cape	146 769	164 487	188 515	180 632	161 714
Western Cape	2 755 339	3 139 800	3 659 198	4 256 902	4 423 997
Total	**8 377 575**	**9 876 623**	**11 659 258**	**13 009 876**	**13 183 119**

Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

As the proportional R&D expenditure that is shown in Figure 7.7 illustrates, the Western Cape surpassed Gauteng with a proportional expenditure of 33.6% in 2018/19 compared to 28.3% in Gauteng.

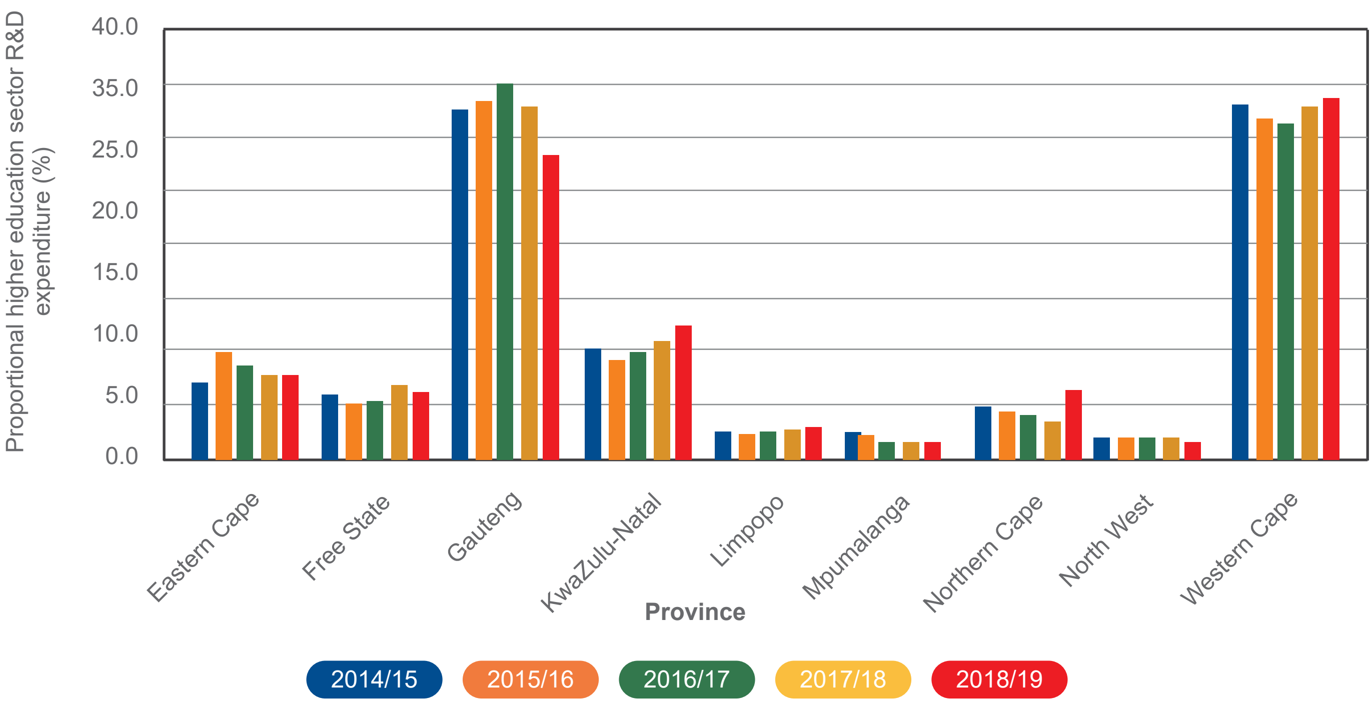


Figure 7.7: Proportional higher education sector R&D expenditure by province
Source: Human Sciences Research Council and Department of Science and Innovation's National Survey of Research and Experimental Development

It is worth noting that, between 2014/15 and 2018/19, Gauteng's portion declined from 32.6% to 28.3%.

7.2.3 Provincial venture capital investments

An important source of funding innovation is venture capital. Access to venture capital is important in developing new innovative businesses. Venture capital is financing that investors provide in the start-up and early growth phases to businesses that they believe have long-term, high-growth potential. These are deals predominantly funded by equity. For start-ups without access to capital markets, venture capital is an essential source of funding.

As Figure 7.8 shows, businesses headquartered in the Western Cape account for the largest share of transactions, both by value (48.2%) and by number (52.6%) of transactions[9]. All venture capital deals still invested are mainly prevalent in Gauteng and the Western Cape, with 90.7% of venture capital rands invested in either one of those two provinces.

Gauteng and the Western Cape are by far the leaders in venture capital investment, which shows that companies in these provinces are able to attract risk capital, which is important for companies with high growth potential.

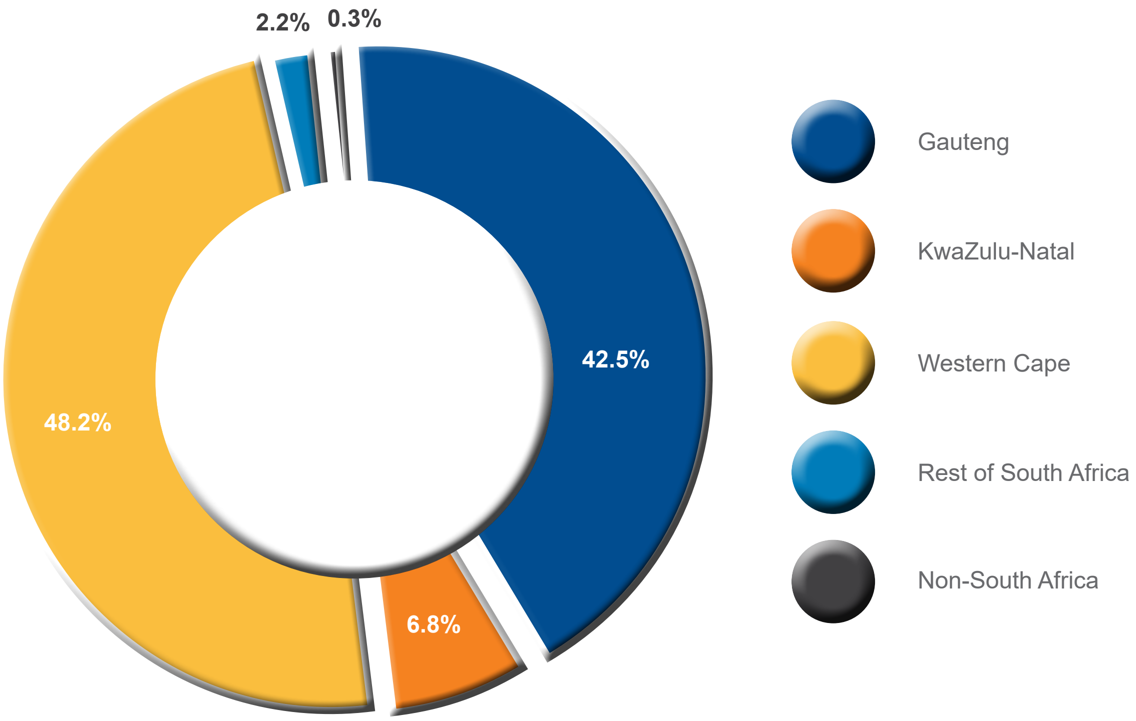


Figure 7.8: Location of investee companies' head offices

Source: Southern African Venture Capital Association Survey, 2019

7.2.4 Provincial science, technology and innovation human capital

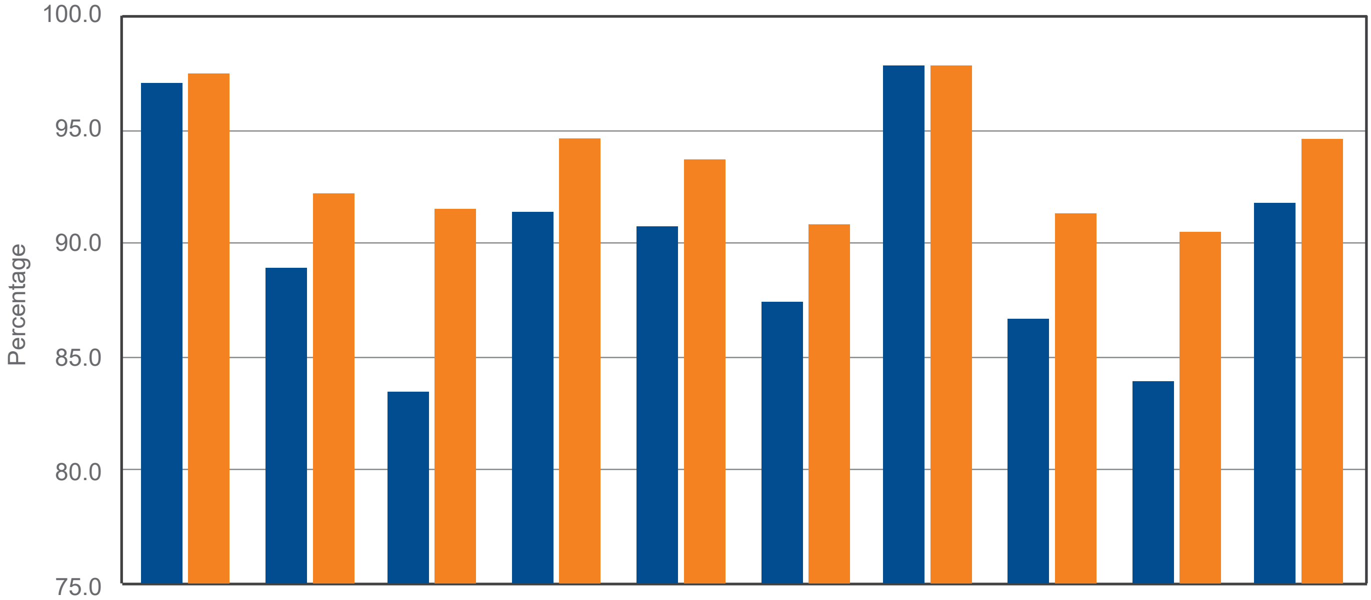
Human capital is a core innovation-related input, and an enabling factor for the effective use of other innovation inputs. The level of literacy and participation in lifelong learning are the indicators that give a sense of the efforts of the workforce to adapt itself to new skill needs. They are proxy for the region's knowledge absorption capacity. Population with tertiary education is a commonly used indicator of the supply of advanced skills, including those related to science and technical fields.

Adult literacy

Figure 7.9 shows the adult literacy rates for persons aged 20 and older, by province. The overall literacy rate among the provinces is high. Nationally, the percentage of literate persons over the age of 20 years increased from 91.9% in 2010 to 94.6% in 2019. The provinces with the highest literacy rates are Gauteng (97.9%) and the Western Cape (97.5%). The lowest literacy rates were observed in Limpopo (90.6%) and the North West (90.9%).

9 Southern African Venture Capital Association Survey 2019

WC	Western Cape	FS	Free State	GP	Gauteng	RSA	South Africa
EC	Eastern Cape	KZN	KwaZulu-Natal	MP	Mpumalanga		
NC	Northern Cape	NW	North West	LP	Limpopo		



	WC	EC	NC	FS	KZN	NW	GP	MP	LP	**RSA**
2010	97.1	89.0	83.6	91.4	90.8	87.5	97.8	86.7	84.0	**91.9**
2019	97.5	92.2	91.6	94.6	93.7	90.9	97.9	91.4	90.6	**94.6**

Figure 7.9: Adult literacy rates for individuals aged 20 years and older by province
Source: Statistics South Africa

Performance in Mathematics and Science by province

Training in Mathematics and Science is increasingly rewarded in the workplace as the demand for low-skilled labour is rapidly declining. High performance standards can also improve the country's global competitiveness. From increasing literacy in STEM subjects, there will be an increase in a skilled workforce for rising career opportunities in STEM-related careers.

In South Africa, the national Department of Basic Education (DBE) shares responsibility for basic schooling with provincial departments, as it is the task of each provincial department to finance and manage its schools directly. Given the responsibilities of the provincial departments of education, it is useful to report on provincial performance.

Table 7.11 displays the provincial performance in Mathematics and Science for 2017–2019.

Table 7.11: Provincial performance in Mathematics and Science

	MATHEMATICS						PHYSICAL SCIENCES					
	2017		2018		2019		2017		2018		2019	
	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE	WROTE	PERCENTAGE ACHIEVED AT 30% OR ABOVE
Eastern Cape	35 994	42.3	36 449	45.5	35 270	41.8	24 805	57.3	24 939	66.5	23 703	70.3
Free State	10 134	70.6	9 722	74.3	9 886	68.5	8 031	77.0	7 876	81.7	7 889	82.7
Gauteng	36 937	67.7	35 279	74.7	35 412	67.8	29 178	70.4	26 763	83.5	25 765	84.0
KwaZulu-Natal	68 463	41.6	61 686	50.6	57 882	48.5	43 005	65.1	40 643	73.6	39 499	74.8
Limpopo	40 723	50.1	39 216	54.9	34 148	53.1	33 584	63.2	31 717	71.8	28 911	72.0
Mpumalanga	24 327	47.8	24 207	54.2	22 621	51.6	19 306	61.6	20 387	70.2	19 679	70.9
North West	10 232	61.2	9 083	68.9	8 783	62.2	8 451	64.3	7 348	78.6	6 939	79.0
Northern Cape	2 796	57.4	2 798	59.0	2 613	56.6	2 344	56.8	2 259	66.9	2 111	69.2
Western Cape	15 497	73.9	15 418	76.0	15 419	70.2	10 857	74.0	10 387	79.5	9 982	81.8
National	**245 103**	**51.9**	**233 858**	**58.0**	**222 034**	**54.6**	**179 561**	**65.1**	**172 319**	**74.2**	**164 478**	**75.5**

Source: Department of Basic Education

Figure 7.10 compares the matric pass rate in Mathematics and Science during 2020. The data shows that, overall, the performance in Mathematics is lower than in Physical Science. The Western Cape (76%), Gauteng (74.7%) and the Free State (74.3%) had the highest pass rates in Mathematics. The lowest performers are the Eastern Cape (41.8%), KwaZulu-Natal (50.6%) and Mpumalanga (54.2%).

In 2020, Gauteng achieved the highest pass rate in Physical Science (84%), followed by the Free State (82.7%) and the Western Cape (81.8%). The Northern Cape had the lowest pass rate (69.2%), followed by North West (70%) and the Eastern Cape (70.3%). The data shows that the provinces need to improve their performance in Mathematics.

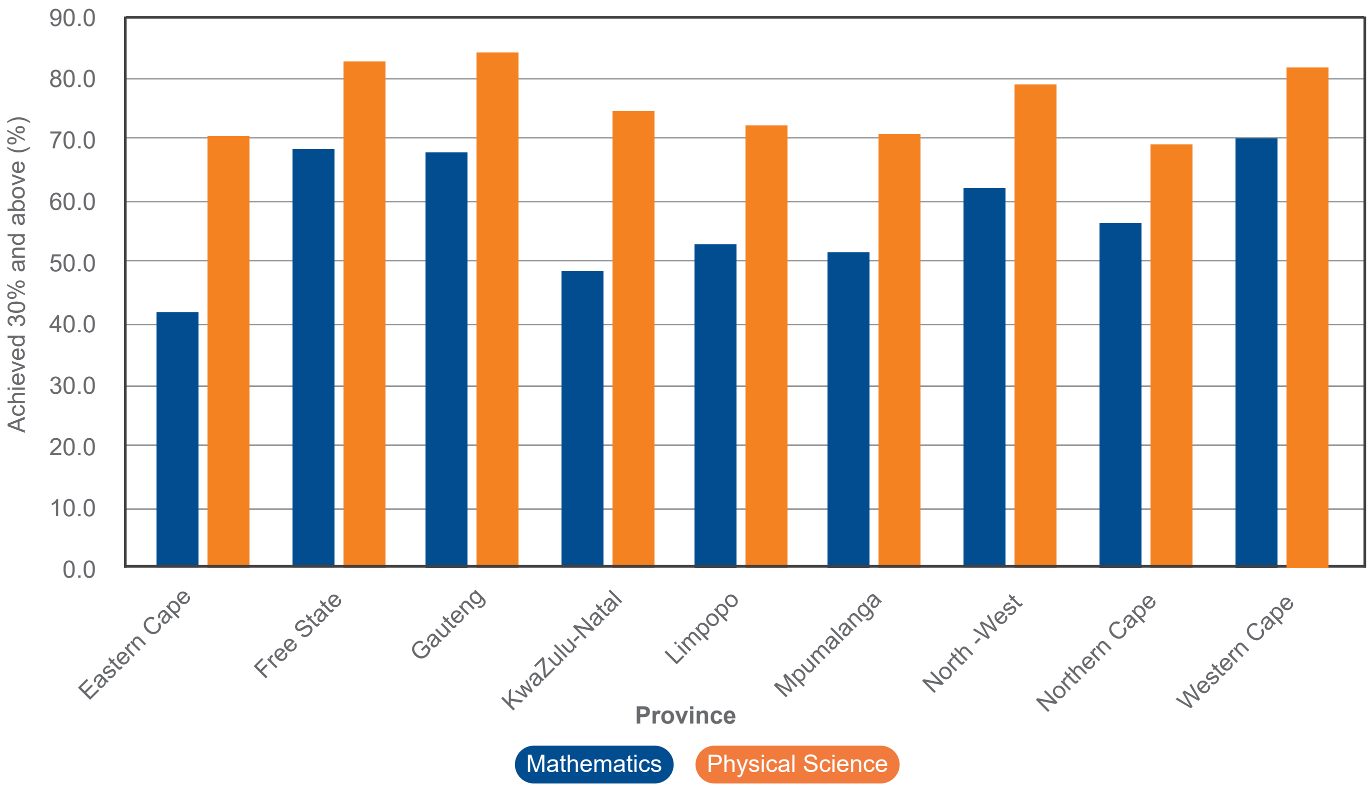


Figure 7.10: Grade 12 Mathematics and Physical Science achievement of 30% or above according to province in 2020

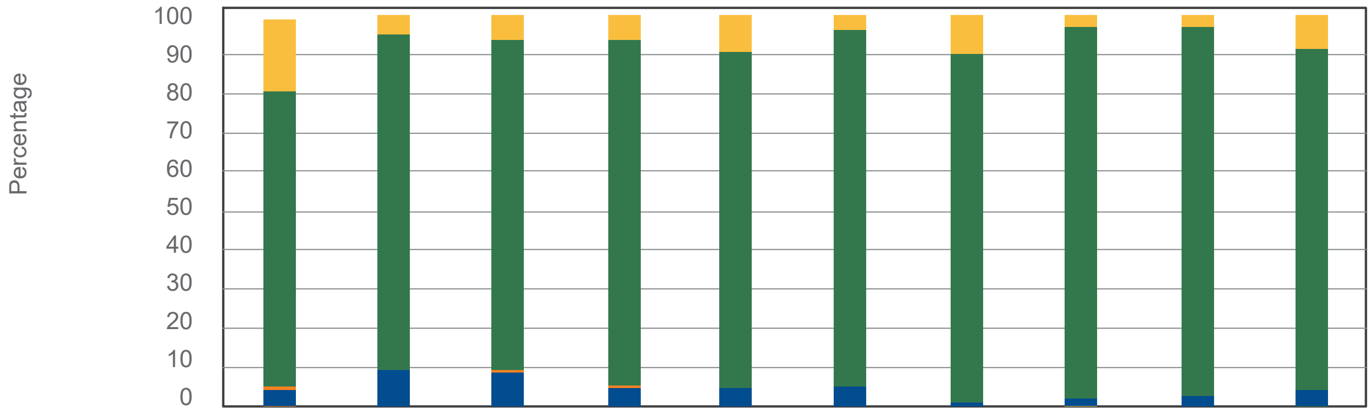
Source: Department of Basic Education

7.2.5 Access to information and communication technology

The role of ICT as a key driver and enabler of innovation has been widely recognised. The advent and development of ICT transformed the economy and society in ways that are evident in everyday life. Communication plays an important role in the fundamental operation of society. It links people and businesses, facilitating communication and the flow of ideas and information, and coordinating economic activities and development.

Figure 7.11 summarises the access and use of the various ICT platforms in South Africa. It shows that households without access to these communication media were most common in the Eastern Cape (9.3%) and Northern Cape (8.7%). It is worth noting that 0.1% of South African households only used landlines. By comparison, 87.8% of South African households exclusively use their cellular phones. The exclusive use of cellular phones was most prevalent in Mpumalanga (95.3%), Limpopo (94.4%) and North West (91.9%). On the other hand, households with higher usage of both cellular phones and landlines were most common in the more prosperous provinces of the Western Cape (18.4%) and Gauteng (9.9%). At national level, only 3.8% of households did not have access to either landlines or cellular phones.

WC	Western Cape	FS	Free State	GP	Gauteng	RSA	South Africa
EC	Eastern Cape	KZN	KwaZulu-Natal	MP	Mpumalanga		
NC	Northern Cape	NW	North West	LP	Limpopo		

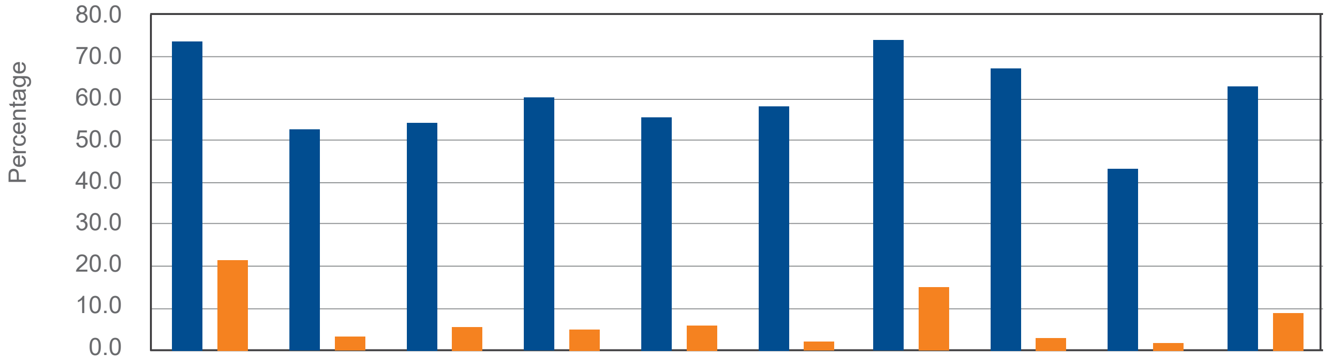


	WC	EC	NC	FS	KZN	NW	GP	MP	LP	RSA
Cell & landline	18.4	4.6	5.9	6.3	9.6	3.2	9.9	2.7	2.9	**8.3**
Only cell	75.7	86.0	85.1	88.9	85.8	91.9	88.9	95.3	94.4	**87.8**
Only landline	0.3	0.1	0.3	0.1	0.0	0.1	0.0	0.0	0.0	**0.1**
None	4.7	9.3	8.7	4.7	4.6	4.8	1.2	2.1	2.8	**3.8**

Figure 7.11: Households who have a functional landline and cellular telephone in their dwellings by province, 2019
Source: Statistics South Africa

Figure 7.12 shows that access to the internet using all available means was highest in Gauteng (74.2%), the Western Cape (73.8%) and Mpumalanga (67.4%), and lowest in Limpopo (43.0%) and the Eastern Cape (52.5%). According to this figure, 9.1% of South African households had access to the internet at home. Access to the internet at home was highest among households in the Western Cape (21.7%) and Gauteng (14.9%), and lowest in Limpopo (1.6%) and the North West (2.3%). Figure 7.12 also shows that 63.0% of South African households had at least one member who had access to, or used the internet at home, work, place of study or at internet cafés.

WC	Western Cape	FS	Free State	GP	Gauteng	RSA	South Africa
EC	Eastern Cape	KZN	KwaZulu-Natal	MP	Mpumalanga		
NC	Northern Cape	NW	North West	LP	Limpopo		



	WC	EC	NC	FS	KZN	NW	GP	MP	LP	RSA
Anywhere	73.3	52.5	54.6	60.2	55.5	58.6	74.2	67.4	43.0	**63.0**
At home	21.7	3.2	5.9	5.4	5.8	2.3	14.9	3.2	1.6	**9.1**

Figure 7.12: Households with access to the internet
Source: Statistics South Africa's 2019 General Household Survey Report

7.2.6 Government innovation support organisations

To support innovation, government has invested in innovation support organisations in the various provinces. These organisations have been created to provide access to innovation support especially to the SMMEs and previously marginalised communities. These include technology stations, incubators, living labs and fabrication labs (fab labs).

Technology stations and the incubator programme are the main support instruments. Technology stations are sector-focused and are located at universities of technology and universities. They facilitate technology transfer between these educational institutions and small enterprises. The Small Enterprise Development Agency (SEDA) Technology Programme is a growing network of incubators and technology support centres with a footprint across all provinces.

There has been no change in the number of technology stations, incubators, living labs and fab labs over the last year (see Table 7.12). A recent development that is worth noting is new support organisations that are initiated and created by the provinces. One of the aims of the government departments is to increase the number of these support organisations.

Table 7.12: Number and type of innovation support organisations in provinces

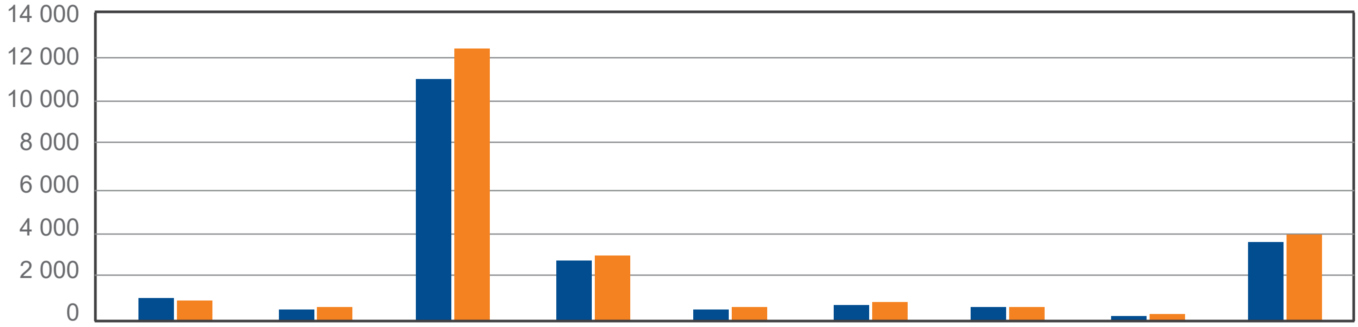
	EASTERN CAPE	FREE STATE	GAUTENG	KWAZULU-NATAL	LIMPOPO	MPUMALANGA	NORTHERN CAPE	NORTH WEST	WESTERN CAPE	TOTAL
Technology stations	3	2	6	2	1	0	1	0	3	18
Incubators	7	6	23	7	7	6	3	3	10	72
Science parks	1	1	1	0	0	0	0	0	1	4
Fab labs	2	1	2	0	1	0	1	1	1	9
Living labs	1	1	0	2	0	0	0	0	1	5
Ekasi labs			10		0	0	0	0	0	10
Innovation lab	0	0	0	1	0	0	0	0	0	1

7.2.7 Impact of innovation at provincial level

Employment in high-tech manufacturing industries

Figure 7.13 illustrates the trends in employment in the high-technology manufacturing and services sectors between 2009 and 2019. As the figure shows, Gauteng is by far the largest employer in this category, followed by the Western Cape and KwaZulu-Natal. Employment in high-technology sectors increased marginally in Gauteng and the Western Cape. High-technology sectors are not significant contributors to employment in the remainder of the provinces.

EC	Eastern Cape	KZN	KwaZulu-Natal	NW	North West
FS	Free State	LP	Limpopo	NC	Northern Cape
GP	Gauteng	MP	Mpumalanga	WC	Western Cape



	EC	FS	GP	KZN	LP	MP	NW	NC	WC
2009	997	510	11 026	2 736	486	688	533	141	3 553
2019	921	584	12 396	2 890	555	783	539	248	3 933

Figure 7.13: Provincial employment in high-tech manufacturing
Source: Quantec

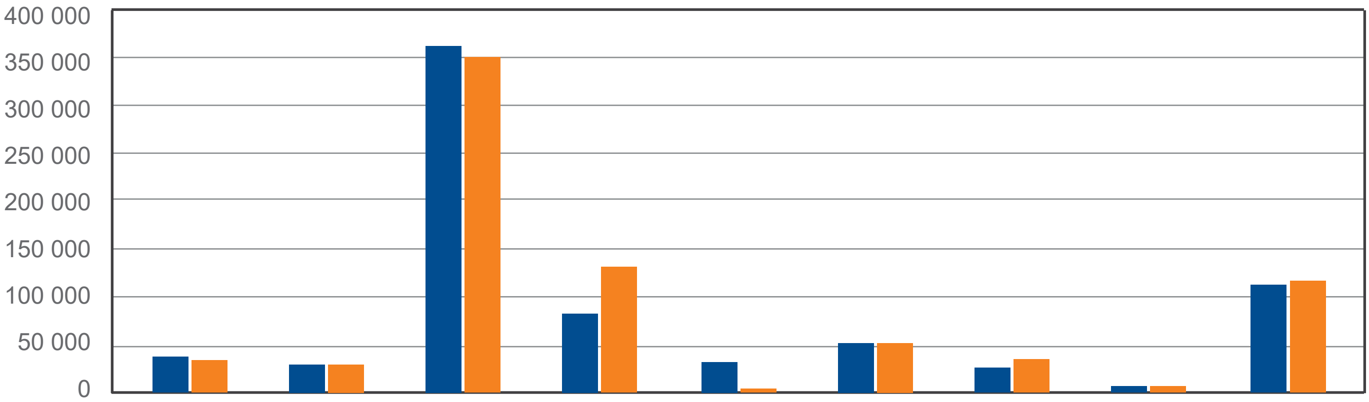
There has been an increase (104%) in employment in this sector in the Northern Cape, although from a low base.

Employment in medium-technology manufacturing industries

Figure 7.14 illustrates employment in medium-techology sectors, which are petroleum products, chemicals, rubber and plastic, other non-metal mineral products, metals, metal products, machinery and equipment, electrical machinery and apparatus, and transport equipment.

Figure 7.14 illustrates the trends in employment in medium-technology sectors. The graph illustrates that Gauteng is the highest employer, followed by KwaZulu-Natal and the Western Cape. KwaZulu-Natal experienced an increase of 58% in employment in this sector in the period under review.

EC	Eastern Cape	KZN	KwaZulu-Natal	NW	North West
FS	Free State	LP	Limpopo	NC	Northern Cape
GP	Gauteng	MP	Mpumalanga	WC	Western Cape



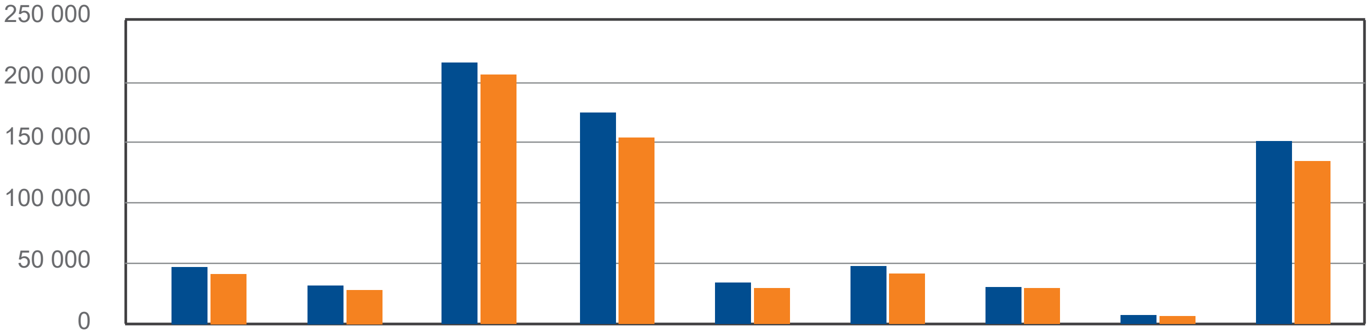
	EC	FS	GP	KZN	LP	MP	NW	NC	WC
2009	38 570	29 856	362 273	82 807	31 383	51 240	25 637	7 613	113 592
2019	34 537	29 854	349 997	130 788	3 064	51 945	36 031	7 426	116 348

Figure 7.14 Provincial employment in medium-technology industries
Source: Quantec

Employment in low-technology industries

As shown in Figure 7.15, Gauteng has the highest employment in low-technology industries, followed by KwaZulu-Natal and the Western Cape. It is worth noting that there has been a decline in employment in this industry between 2009 and 2019. The rest of the provinces lag behind in employment in this sector and have also experienced declines in employment.

EC	**Eastern Cape**	**KZN**	**KwaZulu-Natal**	**NW**	**North West**
FS	**Free State**	**LP**	**Limpopo**	**NC**	**Northern Cape**
GP	**Gauteng**	**MP**	**Mpumalanga**	**WC**	**Western Cape**



	EC	FS	GP	KZN	LP	MP	NW	NC	WC
2009	48 482	33 453	216 841	174 437	34 697	48 790	31 812	7 873	151 627
2019	42 301	29 447	205 859	154 567	30 449	42 180	30 637	7 335	134 609

Figure 7.15: Provincial employment in low-technology Industries
Source: Quantec

Taken together, these results show that, at provincial level, low-technology industries are the main providers of employment, followed by the medium-technology sectors. Overall, there is low employment in high-technology industries, which are associated with high-value products.

APPENDIX A: SCIENTIFIC PUBLICATIONS RELATED TO THE FOURTH INDUSTRIAL REVOLUTION

Internet of Things

ANNUAL NUMBER OF PUBLICATIONS	
2007	1
2008	1
2009	1
2010	1
2011	1
2012	2
2013	2
2014	9
2015	22
2016	40
2017	55
2018	45
2019	81

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Computer science	151
Engineering	138
Telecommunications	55
Science technology other topics	19
Instruments Instrumentation	14
Chemistry	13

MAIN PRODUCERS (2007–2019)	
University of Pretoria	72
Council for Scientific and Industrial Research	49
University of Johannesburg	27
University of the Western Cape	20
University of Cape Town	18
University of South Africa	17
Central University of Technology	16

TOP COLLABORATING COUNTRIES (2007–2019)	
China	33
USA	13
Canada	11
France	9
Germany	7

Additive manufacturing (3D printing)

ANNUAL NUMBER OF PUBLICATIONS	
2007	1
2008	1
2009	0
2010	0
2011	0
2012	0
2013	3
2014	4
2015	7
2016	18
2017	10
2018	15
2019	31

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Engineering	54
Materials science	24
Computer science	8
Robotics	8
Chemistry	5
Energy fuels	5
Automation control systems	4
Science technology other topics	4
Education educational research	3

MAIN PRODUCERS (2007–2019)	
Stellenbosch University	26
University of Pretoria	14
Central University of Technology	10
University of the Witwatersrand	10
University of Johannesburg	9
North-West University	8
University of Cape Town	8

TOP COLLABORATING COUNTRIES (2007–2019)	
USA	7
England	5
Germany	4
Belgium	3
Czech Republic	3
France	3
Scotland	3
Australia	2

Quantum computing

ANNUAL NUMBER OF PUBLICATIONS	
2007	0
2008	4
2009	4
2010	1
2011	2
2012	4
2013	1
2014	11
2015	4
2016	6
2017	5
2018	10
2019	9

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Physics	39
Optics	11
Science technology other topics	9
Computer science	8
Engineering	7

MAIN PRODUCERS (2007–2019)	
University of KwaZulu-Natal	39
University of the Witwatersrand	12
University of Johannesburg	6
Council for Scientific and Industrial Research	5

TOP COLLABORATING COUNTRIES (2007–2019)	
Canada	11
USA	7
England	5
France	5
Germany	5
South Korea	5

Nanotechnology

ANNUAL NUMBER OF PUBLICATIONS	
2007	136
2008	185
2009	229
2010	301
2011	357
2012	457
2013	532
2014	644
2015	750
2016	966
2017	1 045
2018	1 168
2019	1 424

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Chemistry	2 969
Materials science	2 424
Physics	1 750
Engineering	1 213
Science technology other topics	1 182
Polymer science	612
Electrochemistry	549

MAIN PRODUCERS (2007–2019)	
University of Johannesburg	1 409
University of KwaZulu-Natal	989
University of the Witwatersrand	980
Council for Scientific and Industrial Research	966
University of South Africa	796
University of the Free State	649
University of Pretoria	599

TOP COLLABORATING COUNTRIES (2007–2019)	
India	1 050
USA	453
Nigeria	418
China	360
England	301

Robotics

ANNUAL NUMBER OF PUBLICATIONS	
2007	4
2008	10
2009	10
2010	15
2011	12
2012	38
2013	43
2014	39
2015	41
2016	52
2017	59
2018	53
2019	85

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Engineering	191
Computer science	181
Robotics	126
Automation control systems	54
Astronomy astrophysics	29
Science technology other topics	24
Materials science	19
Imaging science photographic technology	13
Environmental sciences ecology	10

MAIN PRODUCERS (2007–2019)	
University of Cape Town	71
University of KwaZulu-Natal	69
Council for Scientific and Industrial Research	62
University of Johannesburg	50
University of Pretoria	37
Tshwane University of Technology	33
University of the Witwatersrand	31
Stellenbosch University	27

TOP COLLABORATING COUNTRIES (2007–2019)	
USA	39
Germany	33
England	32
China	25
France	20
Spain	17
Russia	12

Artificial Intelligence

ANNUAL NUMBER OF PUBLICATIONS	
2007	8
2008	5
2009	8
2010	6
2011	3
2012	12
2013	15
2014	2
2015	18
2016	31
2017	48
2018	41
2019	84

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Engineering	108
Computer science	107
Business economics	26
Energy fuels	25
Science technology other topics	21
Robotics	18
Automation control systems	14
Chemistry	9

MAIN PRODUCERS (2007–2019)	
University of Johannesburg	75
University of KwaZulu-Natal	50
University of Pretoria	37
University of Cape Town	33
Tshwane University of Technology	21
University of the Witwatersrand	15
University of South Africa	14

TOP COLLABORATING COUNTRIES (2007–2019)	
USA	26
England	17
France	14
Australia	11
Iran	11

Autonomous vehicles

ANNUAL NUMBER OF PUBLICATIONS	
2007	5
2008	11
2009	5
2010	9
2011	10
2012	21
2013	35
2014	27
2015	39
2016	49
2017	39
2018	38
2019	68

WEB OF SCIENCE DISCIPLINES (2007–2019)	
Engineering	122
Computer science (Artificial Intelligence)	54
Robotics	51
Transportation	35
Automation control systems	35
Transportation science technology	35
Computer science theory methods	30
Computer science information systems	23
Energy fuels	22

MAIN PRODUCERS (2007–2019)	
University of KwaZulu-Natal	52
University of Cape Town	45
University of Pretoria	44
Council for Scientific and Industrial Research	42
Stellenbosch University	34
University of Johannesburg	32
Tshwane University of Technology	27

TOP COLLABORATING COUNTRIES (2007–2019)	
USA	32
France	28
England	24
China	17
Australia	16

APPENDIX B:
PIPELINE OF RESEARCHERS IN SOUTH AFRICA

	RESEARCHERS (HEADCOUNT)	UNIVERSITY RESEARCHERS	DOCTORAL AND POST-DOCTORAL	RESEARCHERS (TOTAL)	TECHNICIANS	ENROLMENT	GERD (CURRENT) R MILLION	RESEARCHERS/ TECHNICIANS	UNIVERSITY RESEARCHERS, DOCTORAL AND POST-DOCTORAL	GERD/ RESEARCHER	DOCTORAL AND POST-DOCTORAL ENROLMENT
2001/02	19 406	12 626	5 478	24 884	5 139	627 277	7488	5	2.30	264 815	0.87
–	–	–	–	–	–	–	–	–	–	–	–
2003/04	22 760	14 054	8 947	31 707	8 193	717 793	10 083	4	1.57	359 974	1.25
2004/05	27 668	18 270	9 333	37 001	8 641	744 489	12 010	4	1.96	312 310	1.25
2005/06	29 264	18 877	10 002	39 266	8 325	737 472	14 149	5	1.89	284 479	1.36
2006/07	29 304	17 459	10 287	39 591	9 761	741 380	16 521	4	1.70	333 094	1.39
2007/08	29 340	17 008	10 744	40 084	9 476	761 087	18 624	4	1.58	322 972	1.41
2008/09	28 952	16 313	11 003	39 955	9 761	799 490	21 041	4	1.48	337 144	1.38
2009/10	29 255	17 010	11 542	40 797	9 443	837 776	20 955	4	1.47	322 782	1.38
2010/11	25 420	15 553	12 661	38 081	8 559	892 936	20 254	4	1.23	336 703	1.42
2011/12	25 954	16 294	14 699	40 653	9 260	938 201	22 209	4	1.11	356 785	1.57
2012/13	27 314	17 441	15 514	42 828	10 790	953 373	23 871	4	1.12	395 036	1.63
2013/14	28 014	18 212	17 921	45 935	10 800	983 698	25 661	4	1.02	385 522	1.82
2014/15	28 723	18 625	19 756	48 479	12 183	969 155	29 345	4	0.94	424 155	2.04
2015/16	29 455	19 217	22 422	51 877	11 518	985 212	32 337	5	0.86	391 037	2.28
2016/17	33 035	22 302	23 726	56 761	11 346	975 837	35 693	5	0.94	343 454	2.43
2017/18	36 233	24 942	25 607	61 840	11 219	1 036 984	38 725	6	0.97	309 635	2.47
2018/19	33 597	24 618	23 726	57 323	10 545	–	36 784	5	1.04	313 867	–

Sources: Human Sciences Research Council; HEMIS

APPENDIX C: EXPENDITURE BY FIELD OF R&D

	2001/02	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Natural sciences, technology and engineering	88.2	88.2	87.6	87.7	88.2	87.6	87.5	**87.0**	**85.3**	**85.2**	**81.2**	**80.2**	**80.7**	**79.1**	**76.4**	**74.0**	**75.0**
Mathematical sciences	1.3	1.9	1.7	2.1	1.9	1.8	1.9	2.0	2.6	2.9	2.7	2.4	2.2	2.0	2.0	2.3	2.5
Physical sciences	1.3	3.4	3.2	3.9	4.0	4.2	4.5	3.1	1.5	1.5	1.6	1.5	2.0	2.4	2.5	2.8	2.5
Chemical sciences	5.4	5.3	4.0	4.2	3.6	4.2	5.0	4.1	4.3	5.7	6.1	5.1	4.4	4.6	4.9	4.3	4.6
Earth sciences	2.9	2.5	2.2	2.6	2.6	2.8	2.7	1.9	2.0	1.8	2.1	1.9	2.4	2.0	2.2	2.0	2.2
ICT	12.1	10.5	12.8	13.2	14.0	13.9	13.1	15.6	13.9	12.8	8.4	7.8	10.0	12.0	12.6	10.3	9.9
Applied sciences and technologies	15.9	10.2	8.1	10.9	11.0	9.8	9.0	8.3	10.6	9.5	9.4	8.4	5.3	4.7	4.4	4.2	4.2
Engineering sciences	23.0	24.8	23.9	20.8	20.9	22.5	24.4	21.9	17.8	17.0	16.4	16.8	18.7	16.8	12.9	13.1	12.9
Biological sciences	4.1	5.0	4.8	5.0	4.8	3.9	3.5	3.8	6.5	6.1	6.5	6.2	4.8	4.5	4.0	4.0	4.3
Agricultural sciences	8.1	7.4	7.2	6.8	6.9	6.8	5.4	6.9	6.5	7.7	7.6	8.6	9.1	8.0	7.7	7.7	8.3
Medical and health sciences	9.8	13.5	14.8	14.8	15.1	14.0	14.9	16.7	17.1	17.2	17.2	18.2	18.6	19.8	19.2	19.5	21.2
Environmental sciences	1.6	1.5	1.7	1.4	1.3	1.2	1.2	1.1	1.7	2.0	2.5	2.4	1.8	1.2	2.8	2.9	1.2
Material sciences	2.2	1.6	1.6	0.4	1.7	2.0	1.5	1.2	0.5	0.7	0.7	0.7	1.3	0.9	0.8	0.5	0.5
Marine sciences	0.7	0.5	0.5	0.4	0.4	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.7
Social sciences and humanities	**10.6**	**11.8**	**12.4**	**12.3**	**11.8**	**12.4**	**12.4**	**13.0**	**14.7**	**14.8**	**18.8**	**19.8**	**19.3**	**20.9**	**23.6**	**26.0**	**25.0**
Social sciences	8.5	9.6	9.7	9.8	9.4	9.7	9.6	10.7	12.4	12.6	16.8	17.5	17.1	18.7	21.0	23.7	22.4
Humanities	2.1	2.2	2.7	2.5	2.4	2.7	2.8	2.3	2.3	2.2	2.0	2.3	2.2	2.2	2.6	2.3	2.6
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

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