SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS

2019

science
& technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

NACI
NATIONAL ADVISORY COUNCIL ON INNOVATION

SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS

2019

innovation
for a better future

The 2019 South African Science, Technology and Innovation Indicators Report was compiled with the latest available data from various organisations and institutions that were mandated to collect the data. In many instances, the data is not necessarily an update of the previous versions of the report as this is not a statistical report.

We welcome comments and suggestions that would enhance the value of the report to our stakeholders by contributing to our continuous efforts to improve the publication. Please email such comments and suggestions to naci@dst.gov.za.

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LIST OF **ACRONYMS**

ACRONYM	DEFINITION
4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
ARC	Agricultural Research Council
BERD	Business Expenditure on Research and Development
BFR	Big Fast Results
BioPANZA	Bio Products Advancement Network South Africa
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
DBE	Department of Basic Education
DEA	Department of Environmental Affairs
DoH	Department of Health
DST	Department of Science and Technology
DWS	Department of Water and Sanitation
ESCI	Emerging Sources Citation Index
FIFA	International Football Federation
F'SATI	French South African Institute of Technology
GBARD	Government Budget Allocation on R&D
GCI	Global Competitiveness Index
GDP	Gross Domestic Product
GERD	Gross Expenditure on R&D
GFCF	Gross Fixed Capital Formation
GII	Global Innovation Index

ACRONYM	DEFINITION
GMO	Genetically Modified Organism
GNI	Gross National Income
HDI	Human Development Index
HEMIS	Higher Education Management Information System
HEQSF	Higher Education Qualifications Sub-framework
HPRS	Health Patient Registration System
HSRC	Human Sciences Research Council
ICT	Information and Communication Technology
ICT4RED	ICT for Rural Education Development
IoT	Internet of Things
IP	Intellectual Property
IT	Information Technology
LAN	Local Area Network
MEMSA	Mining Equipment Manufacturers of South Africa
MTSF	Medium-term Strategic Framework
MUSD	Maximum Usable Space Design
NACI	National Advisory Council on Innovation
NBES	National Biodiversity Economy Strategy
NBIA	National Business Incubator Association
NDP	National Development Plan
NECT	National Education Collaboration Trust
NIPMO	National Intellectual Property Management Office

ACRONYM	DEFINITION
NPO	Not-for-Profit Organisation
NRF	National Research Foundation
NSC	National Senior Certificate
NSI	National System of Innovation
OECD	Organisation of Economic Cooperation and Development
PBR	Plant Breeders' Right
PHC	Primary Health Care
PV	Photovoltaic
R&D	Research and Development
RDI	Research, Development and Innovation
SADC	Southern African Development Community
SAIMI	South African International Maritime Institute
SAIS	South African Innovation Scorecard
SARB	South African Reserve Bank
SATN	South African Technology Network
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment
SEDA	Small Enterprise Development Agency
SET	Science, Engineering and Technology
SIF	Sector Innovation Fund
SKA	Square Kilometre Array
SPI	Social Progress Index

ACRONYM	DEFINITION
SPII	Support Programme for Industrial Innovation
SMME	Small, Medium and Micro Enterprise
STA	Scientific and Technological Activity
STET	Scientific, Technical and Education Training
STI	Science, Technology and Innovation
STIIL	Science, Technology and Innovation Institutional Landscape
STS	Scientific and Technological Services
TECH4RED	Technology for Rural Education Development
The dti	Department of Trade and Industry
THRIP	Technology and Human Resources for Industry Programme
TIPS	Technology, Innovation, People and System
TT100	Technology Top 100
TVET	Technical and Vocational Education and Training
UCT	University of Cape Town
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UKZN	University of KwaZulu-Natal
USPTO	United States Patents and Trademarks Office
WEF	World Economic Forum
WIPO	World Intellectual Property Organisation
WoS	Web of Science

FOREWORD BY THE **NACI CHAIRPERSON**

Global social inequality – as expressed in the growing gap between rich and poor – is one of humanity's most remarkable and enduring legacies. It is a social relic that, so far, has stubbornly defied the passage of time, holding its place as a constant across both ancient and modern worlds, with such pronounced and obscene visibility that, despite spectacular feats of science and technology by our species over the centuries, remains to this day one of humanity's stunning acts of misachievement.

Contemporary South Africa is a stunning exemplar of this striking historical phenomenon – this, despite the passage of over 25 years of democratic governance, one of the most progressive constitutions in the modern world, the Bill of Rights and numerous efforts to reconstruct the economy. Many, particularly poor black communities, feel left behind, excluded and treated as unimportant, like the counterparts in many other parts of the world, as Ángel Gurría argued, "at the mercy of big impersonal forces of globalisation, technological change, large corporations and financial institutions". Yet the forces are recognisable, definite and historical, the product of human imagination and social power.

For economic and social democracy to emerge successfully in South Africa, it will be crucial to gear and direct the National System of Innovation (NSI) to facilitate and enable far-reaching transformation of the dominant power relations and the socio-economic institutions via which it is regulated and reproduced. Key to this, is the task of building public trust in, and ownership of the nation's science, technology and innovation assets, and their utilisation as enablers of equitable human development. It is for this reason that science, technology and innovation (STI) must, at its core, be grounded in "public good" purposes – strengthening the capacity and integrity of public institutions, rebuilding communities and family households ravaged by the vagaries of neo-liberal economic and social policies, restoring the social agency of individuals, especially the marginalised youth, women and the poor, to build prosperous futures and the creation of a non-racial, equal society. Such imperatives will, we think, require greater levels of participation of not only state and private sector actors, but also civil society and community stakeholders in the emerging STI system.

This STI Indicator Report is written in the context of the build-up of a contradictory confluence of historical conditions both globally and domestically:

- Diminishing natural capital – oil, minerals, natural habitats – requiring totally new approaches to the use of natural capital (e.g. circular economic production)
- Climate change – requiring climate-sensitive regimes of production and consumption
- Rapid population growth (8.5 billion by 2030) – and the challenge of providing for the needs of a growing planetary population
- Spread of democratic ideals and demands for the eradication of inequality – the need to create jobs for all, raise income and redistribute economic assets
- New needs and desires arising from raised living standards and ageing populations – requiring new life enhancing and lifestyle support systems.

Against this background, South Africa is also facing very specific historical and contextual peculiarities:

- An economic order distorted by unsustainable social inequalities expressed across class, ethnicity, gender and spatial lines – itself a consequence of over three centuries of colonial-apartheid rule
- A structurally narrow economic (growth) model historically based on mining-agriculture-finance, with relatively undiversified manufacturing and tertiary sectors
- Dominance of the domestic market by large corporations entrenched in the formal economy, and a highly underdeveloped and largely disarticulated informal economy in townships and rural areas
- Objective realities of the distance of South Africa from the dominant Western and Asia Pacific markets, with weak levels of integration into the highly underdeveloped African markets.

At the same time, we are living through an age of hitherto unprecedented and spectacular advances in the techno-sciences, whose effects are beginning to permeate virtually every sphere of human and planetary life. This includes, inter alia, major advances in information and communication technology, biotechnology, nanotechnology, Internet of Things, robotics, artificial intelligence, machine learning, blockchain and 3D-printing – all of which are beginning to transform industry, products, services, trading systems, markets and entire economies, as well as changing the nature of work itself. While we are only beginning to understand how these technologies work, it seems absolutely crucial to acknowledge its Janus-faced character – both its promises and perils (the “light and shadows”) – to determine the best possible social pathways on the basis of which to ensure the emergence of a fairer, more equal and socially just world in keeping with its ecological limits. The 2019 White Paper on Science, Technology and Innovation promotes innovation as a critical tool for enabling the creation of an inclusive and sustainable economy and society. It advocates for the development of a “whole-of-society” approach to innovation through the evolution of an integrated, dynamic and well-functioning NSI. The 2019 STI Indicators Report is part of NACI’s contribution to building the monitoring, evaluation and learning capability necessary for assessing the state of South Africa’s NSI.

The 2019 STI Indicators Report highlights critical aspects of South Africa’s innovation balance sheet that requires closer scrutiny and debate by all stakeholders. While the set target of 1.5% gross expenditure on research and development (GERD), as a percentage of the country’s gross domestic product (GDP) target, has not been realised (0.82% in 2016/17), government funding of research and development (R&D) was more than its R&D budget by 2016/17. At the same time, aggregate levels of gross private sector investment in R&D has declined in recent years. South Africa experienced an increase of 7% in the number of scientific publications per million inhabitants between 2008 and 2017. It has the highest world share of scientific publications in artificial intelligence (1.01%) and Internet of Things (0.68%), which are examples of research areas related to the Fourth Industrial Revolution (4IR).

Some of the key concerns include South Africa having lost its competitive advantage in terms of medium-technology exports when compared to the average of other upper middle-income countries. It dropped from 44th to 67th position on the Global Competitiveness Index between 2007 and 2017, and from 38th to 58th position on the Global Innovation Index between 2007 and 2017. South Africa ranks low in several indicators on social progress and human development indices, for instance, life expectancy (161st of 189 countries), personal safety (135th), health and wellness (102th) and nutrition and basic medical care (100th).

Moreover, the report should hopefully also raise questions about how to identify and capture a fuller picture of the social innovation landscape – the networks of vastly untapped and often unrecognised social or “grassroots” innovations and innovators, which are often only tangentially connected with the formal NSI. As we move into the future, it will be imperative to better indicators to recognise innovations generated by a significant network of solidaristic, community, non-governmental, cooperative and social enterprise movements.

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

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

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

Derrick Swartz
NACI Chairperson

1. EXECUTIVE SUMMARY

1.1 BACKGROUND

The National Advisory Council on Innovation (NACI) annually produces the South African Science, Technology and Innovation (STI) Indicators Report. The report provides an analysis of the state of STI in South Africa and includes indicators that are critical in the monitoring and evaluation of the South African National System of Innovation (NSI) and its impact and/or contribution towards achieving the country's set national objectives.

In order to adjust timelines and ensure that the publication date of the report is in line with the release date, the current report is titled the *2019 South African STI Indicators Report* (instead of the 2018 report). This change and many other ongoing changes take place as part of NACI's continuous efforts to improve the report so that it remains relevant to its stakeholders. This is also done in response to stakeholder engagement carried out as part of enhancing the report.

1.2 FRAMEWORK FOR THE 2019 SOUTH AFRICAN STI INDICATORS REPORT

The logic framework upon which the *2019 South African STI Indicators Report* is based derives from the South African Innovation Scorecard (SAIS), as adopted by NACI in 2017. This framework categorises STI activities into three broad categories: enablers, firm level activities and outputs.

The SAIS, together with its pillars and sub-pillars, is illustrated in Figure 1.1. This framework, together with other considerations, such as data availability and sources, formed the basis to inform the identification and selection of the various indicators collected in the report. However, stakeholders are cautioned that the framework is utilised only as a guideline, as the actual indicators included in this report may differ slightly from those proposed in the framework. More in-depth discussions, analysis and policy implications are included in the *2019 South African STI Indicators Synthesis Report*.

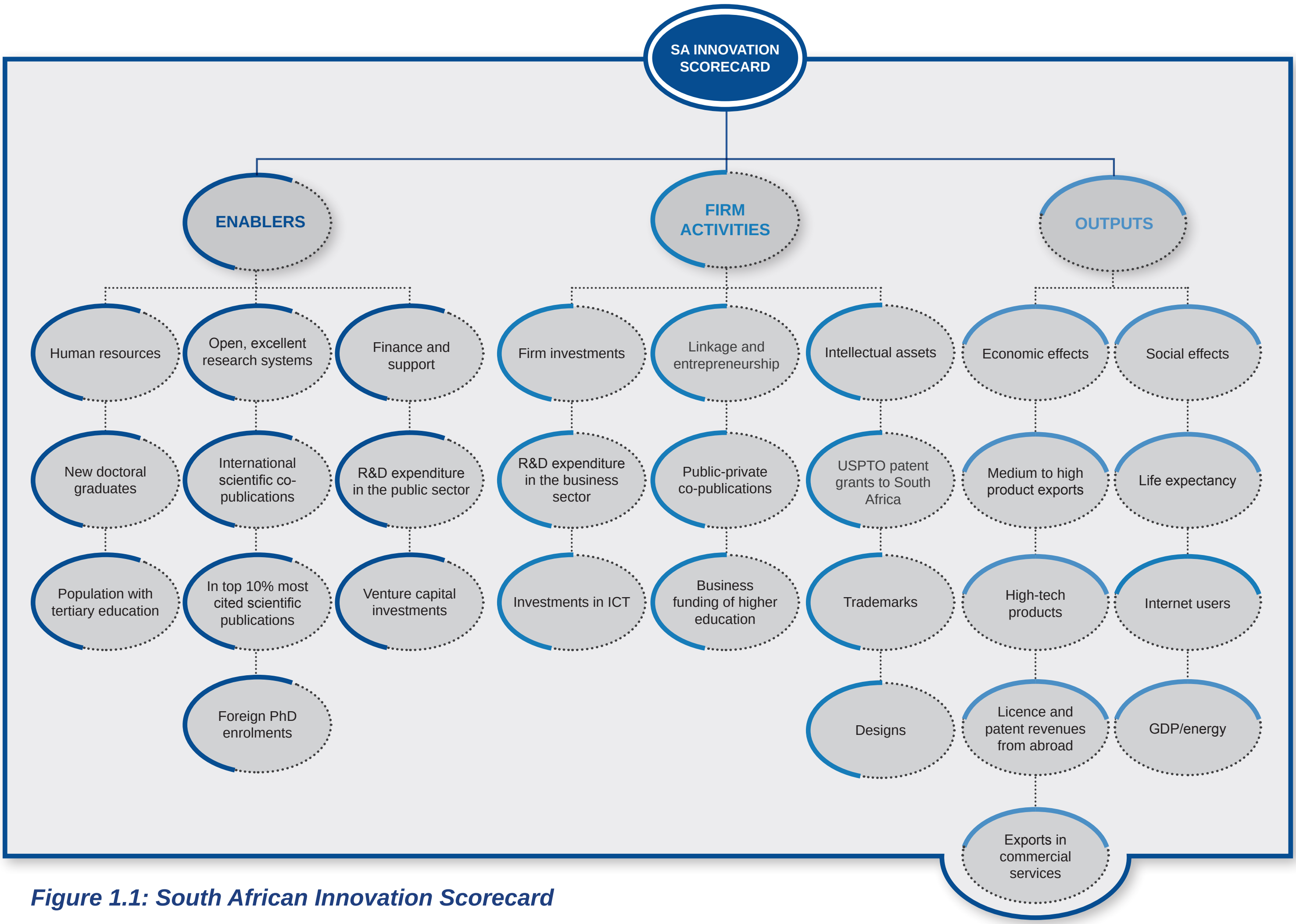


Figure 1.1: South African Innovation Scorecard

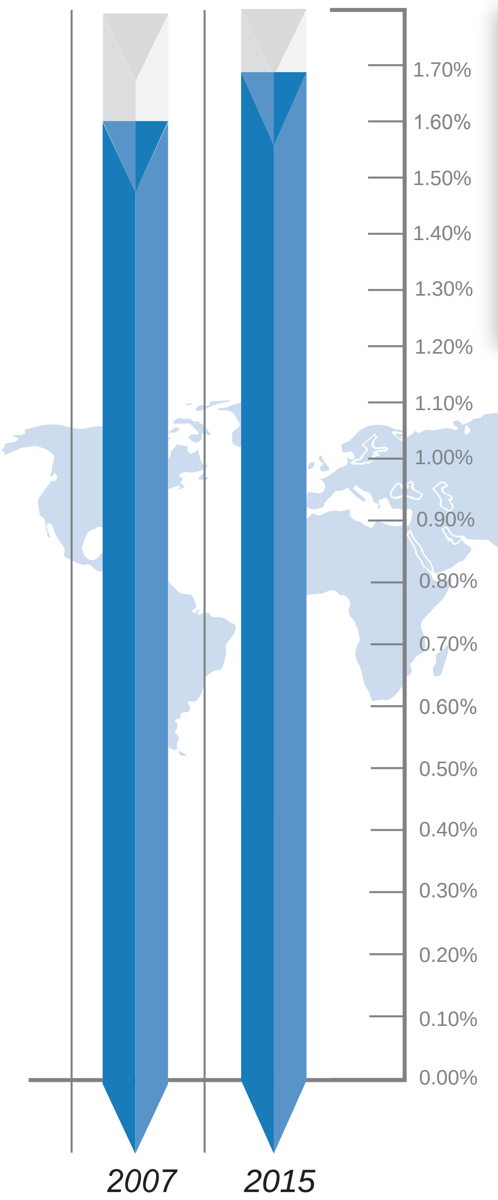
1.3 KEY HIGHLIGHTS OF THE 2019 SOUTH AFRICAN STI INDICATORS REPORT

The main findings of the *2019 South African STI Indicators Report* can be clustered into the following six broad categories: research and development (R&D) expenditure, STI human capital, STI funding and support, scientific publications and patents, innovation and entrepreneurship, and inovation for inclusiveness and social impact.

1.3.1 R&D expenditure

South Africa compared to global figures

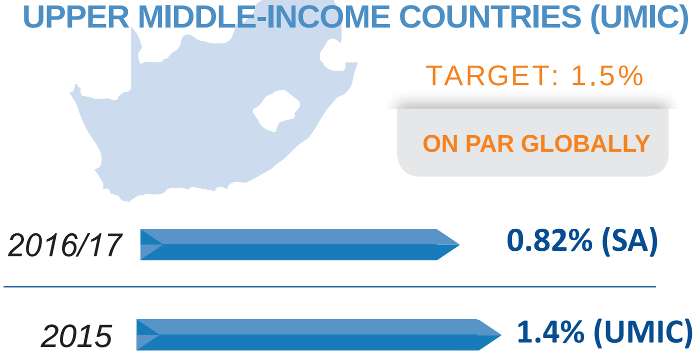
GLOBAL GERD AS A PERCENTAGE OF GDP



0.10%

INCREASE IN GLOBAL GERD AS A PERCENTAGE OF GDP (2007–2015)

SOUTH AFRICAN GERD AS A PERCENTAGE OF GDP TARGET IN RELATION TO OTHER UPPER MIDDLE-INCOME COUNTRIES (UMIC)

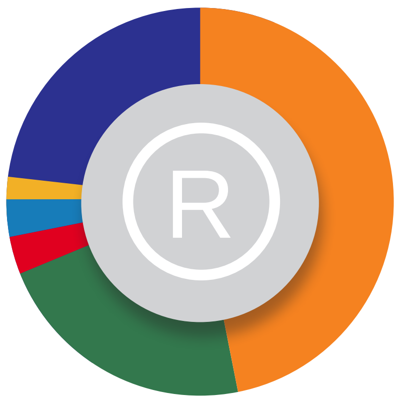


GERD AS A PERCENTAGE OF GDP

GROSS FIXED CAPITAL FORMATION

The rate of increase in BERD is lagging behind that of GFCF

PROVINCIAL R&D EXPENDITURE 2016/17



Gauteng: **46.0%**

Western Cape: **23.3%**

Limpopo: **2.0%**

Mpumalanga: **2.0%**

Northen Cape: **1.5%**

Other provinces: **25.5%**

1.3.2 STI human capital

South Africa compared to global figures

The country matches other upper middle-income countries in terms of the **production** of human capital capacity (formal qualifications), but lags behind in terms of the **deployment, development and know-how** of its human capital.

SOUTH AFRICAN FEMALE RESEARCHERS (2015/16)

RATIO OF MALE TO FEMALE RESEARCHERS
SOUTH AFRICA

RATIO OF MALE TO FEMALE RESEARCHERS
GLOBAL FIGURES

SOUTH AFRICA'S PORTION OF FEMALE RESEARCHERS WAS HIGHER THAN THE GLOBAL AVERAGE DURING THE IDENTIFIED PERIOD

Local challenges

SOUTH AFRICAN RESEARCHERS BY RACE 2016/17

WHITE 50.5%

AFRICAN 32.2%

DURING THE IDENTIFIED PERIOD, THE PORTION OF WHITE RESEARCHERS REMAINED THE LARGEST, WITH AFRICAN RESEARCHERS SECOND

SOUTH AFRICAN RESEARCHERS IN THE BUSINESS SECTOR (DECLINE)

PERCENTAGE OF SOUTH AFRICAN RESEARCHERS EMPLOYED IN THE BUSINESS SECTOR

2008	2016	2019
47.2%	36.1%	29.3%

PROJECTED

POSTGRADUATE EDUCATION AND RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY (SET)

There has been a phasing out of SET-related postgraduate diploma and/or certificate programmes, mainly due to non-alignment to the 2013 Higher Education Qualifications Sub-framework.

SET POSTGRADUATE DIPLOMA AND/OR CERTIFICATE GRADUATES

2009	2017
27.0%	7.0%

SET DOCTORALGRADUATES

2008	2016	2017
67.1%	54.7%	73.3%

1.3.3 STI funding and support

Government contribution

2016/17

R16 428 billion — GOVERNMENT FUNDING OF R&D

R14 851 billion — GOVERNMENT R&D BUDGET

FOR THE FIRST TIME, GOVERNMENT FUNDING OF R&D WAS MORE THAN ITS R&D BUDGET

2010/11	*2016/17*
45.0%	56.1%

GOVERNMENT FUNDING OF R&D FOR THE HIGHER EDUCATION SECTOR

GOVERNMENT FUNDING OF R&D FOR THE HIGHER EDUCATION SECTOR IS ON THE INCREASE, RISING FROM A SHARE OF 45.0% IN 2010/11 TO 56.1% IN 2016/17

2008/09	*2016/17*
9.6%	2.8%

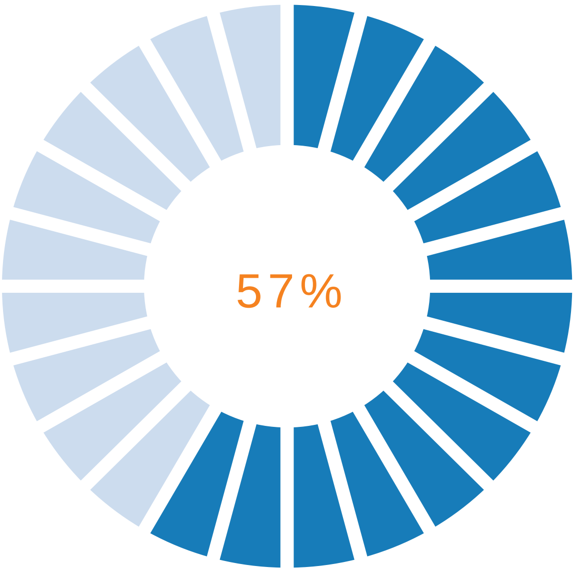
GOVERNMENT FUNDING OF R&D FOR THE BUSINESS SECTOR

GOVERNMENT FUNDING OF R&D FOR THE BUSINESS SECTOR CONTINUED TO DECREASE, DROPPING FROM A SHARE OF 9.6% IN 2008/09 TO 2.8% IN 2016/17

BUSINESS INCUBATION

105

TOTAL ESTIMATED NUMBER OF BUSINESS INCUBATORS IN SOUTH AFRICA



57% of the estimated 105 incubators in South Africa are supported by the public sector.

PROVINCE PARTICIPATION

GP	*KZN*	*WC*
33%	15%	14%

INCUBATOR HOSTS

THE DOMINANT PROVINCES IN RESPECT OF THE NUMBER OF INCUBATORS ARE GAUTENG (GP) (33%), KWAZULU-NATAL (KZN) (15%) AND WESTERN CAPE (WC) (14%)

1.3.4 Scientific publications and patents

South Africa compared to global figures

SOUTH AFRICAN SCIENTIFIC PUBLICATIONS

2008	2017
192	350

NUMBER OF SCIENTIFIC PUBLICATIONS PER MILLION INHABITANTS

SOUTH AFRICA EXPERIENCED AN INCREASE IN THE NUMBER OF SCIENTIFIC PUBLICATIONS PER MILLION INHABITANTS DURING THE IDENTIFIED PERIOD

During the identified period, South Africa produced more scientific publications per million inhabitants than the global average.

307

GLOBAL AVERAGE

SOUTH AFRICAN SCIENTIFIC PUBLICATIONS EXPERIENCED AN ANNUAL GROWTH RATE OF 7% FOR THE PERIOD BETWEEN 2008 AND 2017

FOURTH INDUSTRIAL REVOLUTION (4IR)

For research areas related to 4IR, South Africa has the highest world share of scientific publications in Artificial Intelligence (AI) and Internet of Things (IoT)

AI
1.01%
GLOBAL SHARE

IoT
0.68%
GLOBAL SHARE

PATENTS

PATENT APPLICATIONS PER MILLION INHABITANTS

2008	2017
42	38

DECLINE

THE LINEAR FORECASTING OF THESE IS CONCERNING AS THE COUNTRY IS EXPECTED TO REMAIN AT 37 PATENT APPLICATIONS PER MILLION INHABITANTS FOR A THREE-YEAR PERIOD (2018 TO 2020)

South Africa is lagging behind the average patent applications per million inhabitants for upper middle-income countries.

592

GLOBAL AVARAGE

HIGHEST NUMBER OF PATENTS GRANTED TO UNIVERSITIES AND SCIENCE COUNCILS OVER THE PAST EIGHT YEARS:

38 — CSIR (our future through science)

31 — UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

OPERATION PHAKISA

MAJOR NSI CONTRIBUTIONS

- Ocean economy
- Mining
- Chemical and waste
- Bio-diversity economy

SEVERAL KEY INSTITUTIONS OF THE NSI ARE CONTRIBUTING SIGNIFICANTLY TO THE SUCCESS OF OPERATION PHAKISA

INNOVATION INTEGRATION

±51.35% ***OF TECHNOLOGY TOP 100 ORGANISATIONS INTEGRATE INNOVATION, PEOPLE AND TECHNOLOGY ACTIVITIES AND PRACTICE***

TECHNOLOGY EXPORTS

CAUSE FOR CONCERN

South Africa has lost its competitive advantage in terms of medium-technology exports when compared to the average of other upper middle-income countries. This trend is likely to continue beyond 2020. By the year 2020, South Africa is likely to rank below the lower middle-income countries in terms of the export of low-technology products.

CONTRIBUTION FROM BUSINESS

BUSINESS-LED REGIONAL INNOVATION ECOSYSTEMS ARE MOST PROMINENT IN THE FOLLOWING PROVINCES: FREE STATE, GAUTENG, KWAZULU-NATAL, MPUMALANGA AND NORTH WEST

1.3.6 Innovation for inclusiveness and social impact

South Africa's contribution

OPERATION PHAKISA

planning | implementation | growth

THE CSIR CONTRIBUTED TO OPERATION PHAKISA'S "IDEAL CLINIC" CONCEPT BY DEVELOPING A PROTOTYPE FOR THE DESIGN OF MAXIMUM USABLE SPACE FOR CLINICS.

Human Development Index

113th

Human Development Index

This is relative to the average for upper middle-income countries (90th)

CAUSE: LOW RANKING IN LIFE EXPECTANCY AT BIRTH COMPONENT

161st

OUT OF 189 COUNTRIES

Social Progress Index

Factors that prove challenging for South Africa's ranking:

135th

PERSONAL SAFETY

102th

HEALTH AND WELLNESS

100th

NUTRITION AND BASIC MEDICAL CARE

OUT OF 146 COUNTRIES

RENEWABLE ENERGY

The country lags behind many world economies (including most low-income countries) in adopting renewable energy technologies for electricity production. This indicates the presence of carbon lock-in caused by an abundance of relatively cheap coal deposits in the country.

2. CURRENT TRENDS

2.1 LOCAL TRENDS IN SCIENCE, TECHNOLOGY AND INNOVATION

The National Development Plan (NDP) is a plan for the country to eliminate poverty and reduce inequality by 2030 by uniting South Africans, unleashing the energies of its citizens, growing an inclusive economy, building capabilities, and enhancing the capability of the state and its leaders to work together to solve complex problems. To achieve this vision, the economy needs to grow at a faster pace. Fundamental change is thus required in its structure. Science, technology and innovation have been key enablers of past economic transformations around the world. Going forward, South Africa will need even higher investments in STI due to the emerging 4IR.

2.1.1 Overall performance of the South African NSI

Table 2.1 illustrates selected key indicators arranged according to the three categories: enablers, firm activities and outputs. With regard to the enablers, the higher education sector increased its role in the South African innovation system between 2007 and 2017, as indicated by the huge increase in the proportion of basic research from 20.6% in 2007/08 to 26.7% in 2016/17. The increase in the share of the country's scientific publications in the top 1% (from 1.12% in 2007 to 1.64% in 2017) demonstrates the success of the higher education sector in producing high-quality scientific publications. A key driving factor for this increase in high-quality scientific publications is the large increase in the number of doctoral graduates, from 26.6 per million of the population in 2007 to 53.9 per million of the population in 2017.

During the same period (2007 to 2017), government significantly reduced the funding of business expenditure on research and development (BERD) from 21.67% to 3.07%. It is not clear if this reduction in funding is at the initiative of government or as a result of the slowing down of economic activity experienced by the business sector. The latter might be the real situation as BERD, as a percentage of gross domestic product (GDP), decreased from 0.58% in 2007 to 0.39% in 2017. The deceleration of innovation at firm level resulted in a deterioration in the country's rankings in both the Global Competitiveness Index and the Global Innovation Index.

The technology intensiveness of merchandise exports in 2017 was also low in comparison to 2007. This was the case for the three main categories: high-technology products (from 3.8% in 2007 to 3.2% in 2017), medium-technology products (from 28.6% in 2007 to 27.8% in 2017) and low-technology products (from 9.3% in 2007 to 6.8% in 2017). This shows that the country regressed to become a more resource-intensive economy, which is in contradiction to the plan of being a knowledge-based economy.

The social impact indicators performed well in comparison to the economic impact indicators. Life expectancy at birth increased from 54.7 years in 2007 to 64 years in 2017. Overall, the country's ranking on the Human Development Index improved from a ranking of 191st in 2007 to 113th in 2017.

Table 2.1: NSI performance on selected indicators in 2007 and 2017

	2007	2017 OR LATEST YEAR	SOURCE
Enablers			
Gross expenditure on R&D (GERD) (as a percentage of GDP)	0.88	**0.82**	R&D Survey
Government funding of BERD (percentage)	21.67	**3.07**	R&D Survey
Government funding of higher education R&D expenditure (percentage)	76.25	**79.10**	R&D Survey
Basic research (as a percentage of GERD)	20.6	**26.7**	R&D Survey
SET graduations at public higher education institutions (percentage)	29.5	**29.2**	Higher Education Management Information System (HEMIS)
Doctoral graduations per million of the population	26.6	**53.9**	HEMIS
Number of researchers per million of the population	612.9	**582.5**	R&D Survey
Scientific publications in top 1% (percentage)	1.12	**1.64**	InCites
World share of scientific publications (percentage)	0.51	**0.79**	InCites
World share of patent applications	0.11	**0.07**	World Intellectual Property Organisation (WIPO)

	2007	2017 OR LATEST YEAR	SOURCE
Patents granted to South African inventors by the United States Patents and Trademarks Office (USPTO)	80	182	USPTO
Firm activities			
BERD (as a percentage of GDP)	0.58	0.39	R&D Survey
Global competitiveness ranking	44th	67th	Global Competitiveness Index
Global innovation ranking	38th	58th	Global Innovation Index
Outputs: economic and social			
High-technology exports (as a percentage of all merchandise exports)	3.8	3.2	United Nations Conference on Trade and Development (UNCTAD)
Medium-technology exports (as a percentage of all merchandise exports)	28.6	27.8	UNCTAD
Low-technology exports (as a percentage of all merchandise exports)	9.3	6.8	UNCTAD
Manufacturing value-added (as a percentage of GDP)	16.3	13.7	South African Reserve Bank (SARB)
Human development ranking	191st	113th	United Nations Development Programme (UNDP)
Life expectancy at birth (years)	54.7	64	Statistics South Africa

2.1.2 STI as an enabler for Operation Phakisa projects

Operation Phakisa is an initiative of the South African government, which is intended to fast-track achievements related to the targets of the NDP. The Big Fast Results (BFR) methodology was adopted for this initiative. According to the BFR Institute, this is "a holistic and granular transformation approach designed to deliver a specific goal within a stipulated period of time"[1]. The BFR transformational methodology is carried out according to the following non-linear steps: detailed problem analysis, priority setting, intervention planning and delivery.

As illustrated in Figure 2.1, the seven areas of interest are the oceans economy, health, information and communication technology (ICT) in education, mining, the biodiversity economy, chemical and waste economy, and agriculture, land reform and rural development. These seven areas are currently at different stages of implementation, although the delivery acceleration period was initially set for three years.

Figure 2.1: The focus areas of Operation Phakisa

The outcomes delivery methodology of Operation Phakisa is a good example of leapfrogging mechanisms that developing countries can use to align their outputs with those of developed countries in broad areas of the economy, society, the environment and infrastructure.

1 http://bfrinstitute.com/what-is-bfr/

2.1.2.1 Oceans economy

The following six critical strategic areas have been identified as part of the oceans economy:

- Aquaculture
- Offshore oil and gas exploration
- Marine protection and governance
- Marine transport and manufacturing
- Coastal and marine tourism
- Small harbour and coastal state land development.

The areas of the oceans economy that are showing significant progress are off-shore oil and gas exploration (97% complete) and marine protection and governance (73% complete). The STI-related challenges that were identified during the offshore oil and gas exploration lab included the development of multipurpose research vessels, the support of local content development and the development of a skills strategy roadmap.

In support of the development of research vessels (capabilities) and skills development, the National Research Foundation (NRF), in partnership with the South African International Maritime Institute (SAIMI), established the Operation Phakisa Research Chair in Petroleum Geoscience and Engineering. The 4 kg ZACUBE-2 nanosatellite, developed by the French South African Institute of Technology (F'SATI) at the Cape Peninsula University of Technology (CPUT), was launched on 27 December 2018 as part of a mission to demonstrate a vessel-tracking service to promote the protection of the oceans in South Africa.

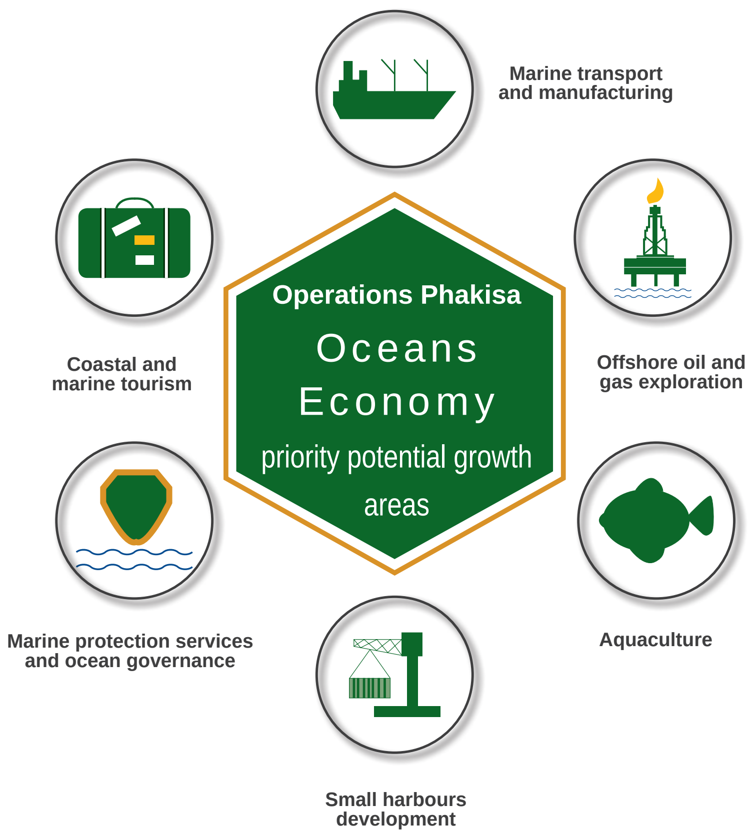


Figure 2.2: Priority potential growth focus areas of the oceans economy

The focus areas of the oceans economy that are still lagging behind are those of coastal and marine tourism (0% complete), marine transport and manufacturing (20% complete) and aquaculture (37% complete). Aquaculture includes the breeding, rearing and harvesting of plants and animals in salt or fresh water[2].

Some of the STI-related activities that support this focus area are the expansion of the Hondeklip Bay Abalone Hatchery of the Department of Science and Technology (DST) (4% complete) and the undertaking of a strategic environmental assessment (SEA) by the Council for Scientific and Industrial Research (CSIR) for the development of aquaculture in South Africa.

2.1.2.2 Health

Operation Phakisa's health focus area convened its lab process in 2014. The participants decided that there was an urgent need to improve the primary health care (PHC) facilities through the "ideal clinic" concept, which includes the following eight workstreams:

2 http://aquasea.csir.co.za/

- Service delivery (optimal delivery of quality health care)
- Waiting times (reduction of waiting times to a maximum of three hours)
- Infrastructure (development of an effective infrastructure roll-out plan to ensure that all PHC facilities have world-class infrastructure that is delivered on time and is well maintained for the future)
- Human resources for health (creating an equitable distribution of well-trained workers with the required capabilities)
- Financial management (implementing a realistic budgeting process that accurately forecasts the funding requirements of facilities, allocates resources equitably and improves financial accountability)
- Supply chain management (the continuous availability of medicines and supplies, reduction of costs for the procurement and distribution of commodities, and improving the turnaround times for the delivery of non-standard stock items)
- Institutional arrangements (developing effective institutional arrangements and inter-governmental agreements)
- Scale-up and sustainability (developing a national scale-up framework and an implementation plan to enable all 3 507 PHC facilities in South Africa to achieve "ideal clinic" status).

As part of the "ideal clinic" delivery component, the CSIR contributed to the study by developing a maximum usable space design (MUSD) prototype for clinics. According to the 2015 White Paper on National Health Insurance, the national Department of Health (DoH), in partnership with DST and CSIR, initiated the health patient registration system (HPRS) in 2013.

The HPRS supports the tracking of the utilisation of health care facilities, and linking these to electronic health records to create a register of patients. This should contribute to improved health sector planning, decision making and better service delivery.

3 2.1.2.3 Education

The ICT in education lab identified the following five streams:

- Connectivity (servers, internet and wireless access points)
- Devices (tablets, laptops, computers and projectors)
- Professional teacher development initiatives
- Digital content development and distribution
- E-administration

An analysis by the Portfolio Committee of the 2018 report of the Department of Basic Education (DBE) on the ICT rollout found that the following initiatives have been established in support of e-education:

- The publication of a 2004 White Paper on e-education (to guide the DBE's approach to e-education and the integration of ICT into teaching and learning)
- The development of a 2007 guideline on teacher training and professional development in ICT
- A feasibility study by KPMG in 2009 to determine whether an e-education initiative was in the best interest of schools
- A school principals' guideline for managing ICT in South African schools
- The development of the 2012 schools guideline for ICT hardware specifications

The 2016 report of the National Education Collaboration Trust (NECT) on the status of ICT in education in South Africa found that, although the strategy and policy are well defined, its implementation is limited and progress is slow. In addition, the objectives are defined at a high level and are not context specific. There is no clear pathway from the current status to a common objective. Gaps at a strategy and policy level result in an environment in which change is driven by external solution providers.

In response to the above challenges, the Technology for Rural Education Development (TECH4RED) initiative (between the DST, DBE, the Eastern Cape Department of Education and the Department of Rural Development and Land Reform) was announced in the Cofimbava schools district. The aim was to contribute to the improvement of rural education through technology-led innovation. The ICT4RED aspect of TECH4RED aimed to investigate how modern ICT, such as tablets and mobile phones, can support teaching and learning in schools and prepare children for the future.

ICT4RED has the following 12 core components:

- Project management (financial management, procurement and implementation management)
- Change management (leadership, e-readiness and e-maturity)
- Teacher professional development (approach and models, pedagogy and integration in the classroom)
- School ICT infrastructure (devices, wireless local area network (LAN), storage and power)
- Connectivity (Wi-Fi mesh or satellite backbone connectivity and internet)
- Operations management (logistics support, maintenance and distribution)
- Content (standards and conventions creation, customisation and dissemination)
- Community engagement (learners, parents, teachers and the community)
- Research and development (academic research, implementation guidelines and evidence-based policy support)
- Communication (marketing strategy, social media strategy and knowledge management)
- Stakeholder management (district or circuit officials, and local and provincial leadership)
- Monitoring and evaluation (learners, teachers and schools).

4 *2.1.2.4 Mining*

The 2015 lab for the mining component of Operation Phakisa resulted in 15 streams (see Figure 2.3) that can be subdivided into three requirements for the mining sector:

- Addressing current challenges
- Stabilising the cluster
- Building the foundation for the future cluster

These areas address challenges within the South African mining sector such as job losses, the increasing number of industrial actions, the flight of foreign investments, low commodity prices, the declining contribution of mining to GDP, the decline in gold production, the depletion of resources (such as gold), the legacy of environmental problems (such as acid mining drainage) and slow transformation within the sector.

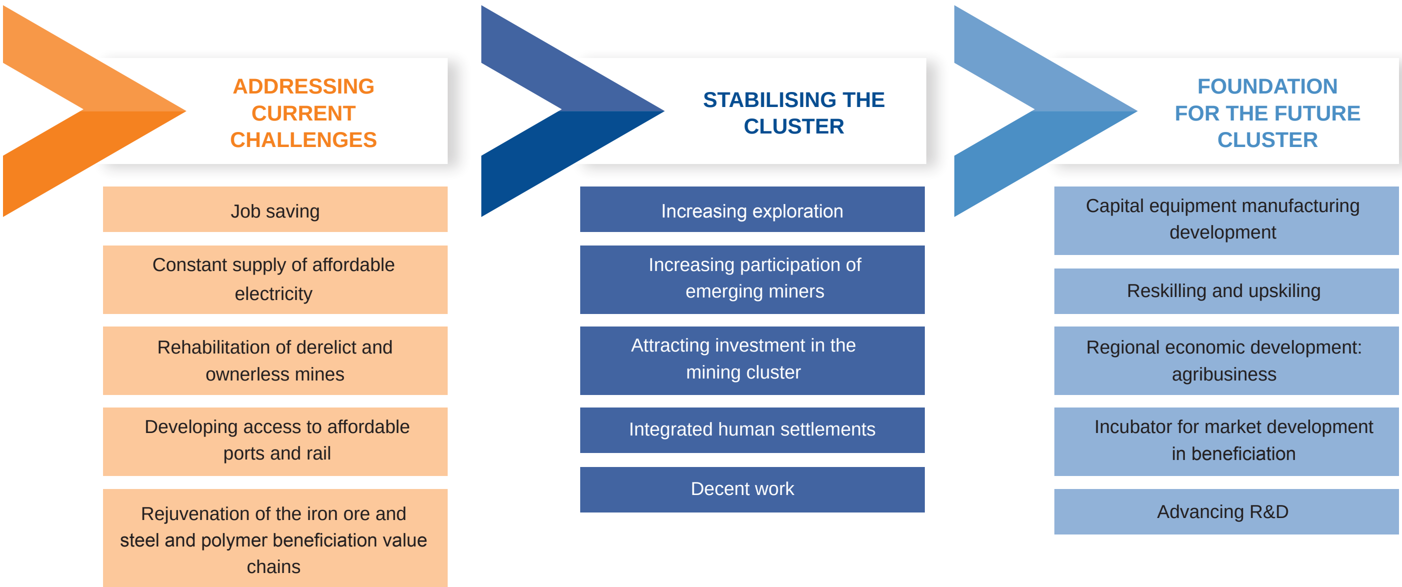


Figure 2.3: Mining focus areas from Operation Phakisa's 2015 lab outcome

Whereas most of these workstreams address the current challenges faced by the mining sector, which might not necessarily be resolved through STI interventions, stakeholders of the NSI are contributing towards building the foundations of the future mining sector through R&D and the development of manufacturing. Some of these initiatives are the launch in 2018 of the Mandela Mining Precinct and the Mining Equipment Manufacturers of South Africa (MEMSA). These two initiatives are both hosted at the CSIR's Johannesburg facilities.

5 2.1.2.5 Biodiversity economy

The lab for a biodiversity economy was convened in 2016 as part of the National Biodiversity Economy Strategy (NBES) of the Department of Environmental Affairs (DEA). The two workstreams that resulted from this process are bioprospecting and wildlife.

The seven initiatives prioritised for the bioprospecting stream cover areas such as change of legislation, easing regulatory burdens, coordination of the sector and innovation, as well as the promotion of mass cultivation and the sustainable harvesting of indigenous plant species. The Bio Products Advancement Network South Africa (BioPANZA), with the tri-chairmanship of DEA, DST and the Department of Trade and Industry (the dti), will be a vital platform for coordinating the bioprospecting sector and providing innovation support. BioPANZA-related activities were 39% complete[3] at the time of writing this report and were gazetted by government in October 2018.

The 15 initiatives that form part of the wildlife stream can be categorised as follows:

- Facilitating transformation
- Driving growth through the promotion of value and products
- Creating an enabling environment for the wildlife sector

In support of this workstream, the CSIR developed a predictive modelling tool that can be used for counter-poaching operations in the Kruger National Park. The intention is to upscale the use of this tool and apply it in other national and provincial parks[4].

6 2.1.2.6 Agriculture, land reform and rural development

The three commodity-based workstreams that resulted from the agriculture, land reform and rural development focus area are grains (unlocking finance, integrated value chain and know-how), horticulture (unlocking water to expand production and an inclusive value chain model) and livestock (fortified veld management for sustainable production, skills and knowledge upgrading, enhanced animal health, livestock traceability (animal identification) and access to commercial value chains).

The following four enablers were identified along with these three workstreams:

- Land reform (financial partnerships for accelerated and sustainable land reform, the sustainable fast-tracking of the settlement of outstanding claims, accelerated land development and redistribution, promoting and protecting the rights of persons with insecure tenure and the creation of district land reform delivery centres)
- Producer support (agricultural development funding reform, dynamic business model support, legislation harmonisation and the creation of a centralised virtual platform to connect producers to service providers)
- Labour (a decent work programme, house and land ownership, legal compliance and demand-led skills development)
- Rural development (strategic leadership and coordination, basic services and rural enterprise development).

7 2.1.2.7 Chemical and waste economy

As illustrated in Table 2.2, the 2017 chemical and waste economy lab resulted in four workstreams and an associated 20 initiatives (with two cross-cutting initiatives).

3 www.operationphakisa.gov.za
4 www.csir.co.za

Table 2.2: Workstreams and initiatives for the chemical and waste economy

BULK INDUSTRIAL WASTE	MUNICIPAL WASTE	PRODUCT DESIGN AND WASTE MINIMISATION	CHEMICALS	CROSS-CUTTING INITIATIVES
Increase ash uptake for alternative building materials	Introduce an e-waste levy to increase collection rate	Develop capacity for minimisation of food loss by agri-stakeholders	Establish a refrigerant reclamation and reusable cylinder industry	Coordinate small, medium and micro enterprise (SMME) development opportunities
Accelerate innovation and commercialise existing R&D	Unlock government ICT legacy volumes	Launch a consumer awareness campaign to use and consume ugly food	Ban the import of harmful chemicals (leaded paint or paint pigments)	Roll out national awareness campaigns
Export ash and ash products	Achieve a minimum of 50% of households separating at source by 2023	Formalise packaging industry producer responsibility plans	Collect and dispose of stockpiles of harmful substances (asbestos, mercury)	
Zero-sewage sludge to landfill	Introduce materials facilities and pelletisation plants to increase plastic recycling rates	Establish refuse-derived fuel plants across South Africa		
Towards zero-meat production waste to landfill by 2023	Produce building aggregates and construction inputs from rubble and glass			

Overall, the waste-related initiatives are geared towards the promotion of the South African economy and the creation of jobs, while reducing any adverse environmental impacts on the system. The chemical-related initiatives are aimed at replacing banned, soon to be banned and other hazardous substances with less harmful substitutes that are ideally produced locally.

The DST's 2011 Waste Research, Development and Innovation (RDI) Roadmap provided a useful landscape analysis that supplied relevant background information for the chemical and waste economy lab process.

2.2 GLOBAL TRENDS IN SCIENCE, TECHNOLOGY AND INNOVATION

In this section, South Africa is benchmarked against a wide range of STI components.

2.2.1 R&D expenditure

World GERD, as a percentage of GDP, increased slightly from 1.6% in 2007 to 1.7% in 2015 (see Table 2.3), representing an average increase of 0.8% per annum.

Table 2.3: Global trends in GERD as a percentage of GDP

	2007	2008	2009	2010	2011	2012	2013	2014	2015	FORECAST 2016	FORECAST 2017	FORECAST 2018
World average	1.60	1.60	1.65	1.62	1.64	1.65	1.67	1.69	1.70	1.71	1.72	1.73
Low-income countries	0.27	0.27	0.29	0.32	0.33	0.35	0.37	0.36	0.36	0.39	0.41	0.42
Lower middle-income countries	0.47	0.48	0.49	0.48	0.49	0.46	0.45	0.43	0.41	0.42	0.41	0.41
Upper middle-income countries	0.92	0.97	1.11	1.14	1.17	1.25	1.31	1.36	1.40	1.48	1.54	1.60
High-income countries	2.22	2.30	2.34	2.31	2.35	2.35	2.38	2.40	2.41	2.44	2.46	2.48
South Africa	**0.88**	**0.89**	**0.84**	**0.74**	**0.73**	**0.73**	**0.72**	**0.77**	**0.80**	**0.82**	**0.70**	**0.68**

Source: Institute for Statistics of the United Nations Educational, Scientific and Cultural Organisation (UNESCO); NACI's linear forecast

The countries that contributed most to this increase were the upper middle-income and low-income countries with annual average increases of 5.5% and 3.7% respectively. The upper middle-income countries' GERD forecast, as a percentage of GDP in the medium term, indeed supports the validity of South Africa, using a target of 1.5% of GDP as set out in the Medium-term Strategic Framework (MTSF).

The medium-term outlook for South Africa is likely to improve, based on a positive trend over the past four years, although the forecast values are low, based on a low overall economic growth rate over the past decade. However, a gradual increase of GERD, as a percentage of GDP between 2013 and 2016, provides some expectation that this negative trend can be reversed.

2.2.2 Human capital development and deployment

High-income countries continue to dominate in terms of development and their human capital's level of expertise (see Table 2.4).

Table 2.4: The World Economic Forum's human capital equivalent ranking by income group

	RANKING OUT OF 130 COUNTRIES				
	OVERALL HUMAN CAPITAL	CAPACITY	DEPLOYMENT	DEVELOPMENT	KNOW-HOW
High-income countries	32	48	64	24	24
Low-income countries	113	116	34	119	105
Lower middle-income countries	94	85	74	93	96
Upper middle-income countries	73	67	87	74	79
World average	67	76	70	68	53
South Africa	**87**	**65**	**109**	**90**	**86**

Source: World Economic Forum's 2017 Global Human Capital Report (interpreted by NACI)

The World Economic Forum (WEF) defines human capital development as the formal education of the next-generation workforce and the continued upskilling and reskilling of the current workforce (see Figure 2.4).

On average, the upper middle-income countries rank much higher on human capacity, which measures the attainment of formal education at different levels. South Africa, classified by the World Bank as an upper middle-income country, is also doing well with regard to human capacity, with a ranking that is higher than the world average, and also higher than the average ranking of upper middle-income countries.

Although human capital development is much lower in low-income countries, their human capital deployment ranks much higher. This is an area where South Africa is not performing well. This can possibly be ascribed to the country's high unemployment rate.

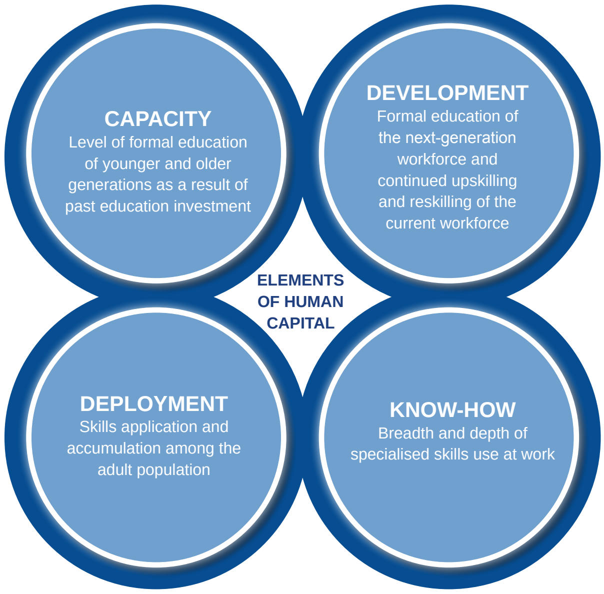


Figure 2.4: Definitions of the World Economic Forum's human capital pillars

Source: World Economic Forum's 2017 Global Human Capital Report

2.2.3 Scientific publications

Between 2008 and 2017, global scientific publications per million inhabitants increased at an average annual rate of 3.6%. The countries that are above this rate are the low middle-income and upper middle-income countries, with rates of 8.6% and 8.4% respectively. South Africa, as an upper middle-income country, experienced a growth rate of 7.0%. Although this rate is comparatively low, the country has a high number of scientific publications per million inhabitants (350 in 2017) (see Table 2.5). This trend is set to continue in the medium term.

Table 2.5: Global trends in scientific publications per million inhabitants

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
World average	334	355	363	380	398	416	435	448	464	458	488	503	518
Low-income countries	93	98	102	106	114	115	121	125	125	124	133	137	141
Lower middle-income countries	32	34	36	39	43	48	55	59	65	68	71	76	80
Upper middle-income countries	150	170	176	200	220	237	257	275	298	307	329	347	365
High-income countries	1 490	1 570	1 611	1 661	1 724	1 791	1 857	1 895	1 943	1 894	2 021	2 071	2 122
South Africa	**192**	**211**	**217**	**246**	**276**	**283**	**307**	**324**	**353**	**350**	**381**	**400**	**419**

Source: Clarivate Analytics's InCites; NACI's linear forecast

The rate of increase of scientific publications per million inhabitants among the high-income and low-income countries (2.7% and 3.3% respectively) is below the world average. As a result, by 2020, high-income countries are expected to see a decrease in their world share of scientific publications to 67.5% (from 68.6% in 2017). For the same period, the share of the upper middle-income countries will increase from 22.9% to 23.8%.

2.2.4 Intellectual property protection

The number of patent applications per million inhabitants for high-income countries is much higher than that of scientific publications (see Table 2.6), but the rate of increase has been lower. As a result, between 2017 and 2020, patent applications are forecast to grow by only 3.9% per annum to reach a forecast value of 1 294 patents per million inhabitants. The upper middle-income countries are expected to see their patent applications grow at a faster pace to close the gap in respect of high-income countries.

Unfortunately, this will not be the case for South Africa, all other factors being equal. The number of patents per million inhabitants is expected to remain stagnant at 37 until 2020. This stagnation in the number of patent applications is a characteristic of low-income and lower middle-income countries.

Table 2.6: Global trends in patent applications per million inhabitants

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
High-income countries	1 208	1 132	1 167	1 176	1 218	1 237	1 241	1 250	1 250	1 245	1 272	1 283	1 294
Low-income countries	15	16	16	15	16	15	15	15	14	14	14	14	14
Lower middle-income countries	24	22	25	26	26	26	26	27	26	27	28	28	28
Upper middle-income countries	179	182	214	270	322	389	427	495	581	592	647	698	749
World average	285	271	288	308	332	357	369	392	420	421	444	462	480
South Africa	**42**	**39**	**39**	**34**	**32**	**41**	**42**	**38**	**36**	**38**	**37**	**37**	**37**

Source: World Intellectual Property Organisation's IP Statistics Data Centre; NACI's linear forecast

2.2.5 Global Innovation Index

The Global Innovation Index (GII) is published annually. Its 80 indicators explore a broad vision of innovation, including the political environment, education, infrastructure and business sophistication[5]. The country's 58th ranking on the 2017 GII is better than the average for upper middle-income countries (see Table 2.7). Recorded good performance on innovation inputs seems to be the main contributor.

5 https://www.globalinnovationindex.org/

Table 2.7: GII's equivalent ranking by income group

	RANKING OUT OF 127 COUNTRIES			
	OVERALL GII	INNOVATION EFFICIENCY RATIO	INNOVATION INPUTS	INNOVATION OUTPUTS
High-income counties	30	39	26	30
Low-income countries	117	100	110	115
Lower middle-income countries	88	67	96	79
Upper middle-income countries	66	75	66	67
World average	51	60	51	53
South Africa	**58**	**83**	**48**	**65**

Source: 2018 Global Innovation Index (interpreted by NACI)

However, the innovation efficiency ratio is lower than that of lower middle-income countries due to a failure of the NSI's actors to use inputs, such as excellent market sophistication, more efficiently. The innovation competitive strength of high-income countries lies in the strong linkage between their inputs and outputs, hence their innovation efficiency ratio has a high equivalent ranking.

In terms of the pillars of the GII (see Table 2.8), the equivalent rankings of innovation outputs show that South Africa is performing relatively well in terms of knowledge and technology outputs in comparison to the average demonstrated by upper middle-income countries. The main driver behind this is a good record of accomplishment in scientific publications and citations. However, a low ranking in respect of creative outputs reduces the overall ranking on outputs. This is also the case for other upper middle-income countries. Creative outputs include indicators such as online creativity, intangible assets and creative goods and services.

In relation to a world average ranking of 64 for infrastructure, South Africa is positioned at 84th. Indicators included in this pillar cover areas such as ICT, general infrastructure and ecological sustainability.

Table 2.8: Equivalent ranking of the GII pillars by income group

	INNOVATION INPUTS					INNOVATION OUTPUTS	
	INSTITUTIONS	HUMAN CAPITAL AND RESEARCH	INFRA-STRUCTURE	MARKET SOPHISTICATION	BUSINESS SOPHISTICATION	KNOWLEDGE AND TECHNOLOGY OUTPUTS	CREATIVE OUTPUTS
High-income countries	29	30	29	27	29	26	30
Low-income countries	102	106	111	112	103	108	112
Lower middle-income countries	96	92	94	79	92	71	87
Upper middle-income countries	70	69	70	67	64	66	71
World average	57	56	64	58	48	51	55
South Africa	**53**	**64**	**84**	**23**	**47**	**55**	**76**

Source: 2018 Global Innovation Index (interpreted by NACI)

2.2.6 Global Competitiveness Index

The Global Competitiveness Index (GCI) 2017–2018 presents a framework and a corresponding set of indicators in three principal categories (sub-indices) and 12 policy domains (pillars) for 137 economies[6]. As illustrated in Table 2.9, South Africa's 67th ranking on the GCI in 2018 is above the average of upper middle-income countries (74th) and above the world average (69th). Two areas of strength for South Africa are markets (31st) and innovation capability (46th). It is worth noting that this ranking for the markets component of the GCI is even above the average of high-income countries (33rd). The markets component includes the factors of production (labour and capital markets) and market attractiveness (market size and product market).

According to the 2018 GCI report, South Africa's innovation capability is advanced, but limited somewhat by insufficient R&D.

Table 2.9: GCI equivalent ranking by income group

	RANKING OUT OF 140 COUNTRIES				
	OVERALL GCI	ENABLING ENVIRONMENT	HUMAN CAPITAL	MARKETS	INNOVATION ECOSYSTEM
High-income countries	29	32	31	33	31
Low-income countries	122	124	120	125	118
Lower middle-income countries	101	98	103	93	101
Upper middle-income countries	74	77	78	64	72
World average	69	69	87	61	55
South Africa	**67**	**66**	**114**	**31**	**46**

Source: 2018 GCI (interpreted by NACI)

Another area where South Africa is performing well (66th) relative to the average of upper middle-income countries (69th) is in respect of the enabling environment. The pillars under this component include institutions, infrastructure, ICT adoption and macro-economic stability (see Table 2.10).

A competitiveness enabler that needs significant improvement in South Africa is ICT adoption. Only 54% of the adult population has access to the internet and only 70 out of 100 people have subscribed to mobile broadband services. On the other hand, South Africa has one of the highest mobile telephone subscriptions per 100 people. A main challenge is therefore access to broadband internet to allow graduates and others access to education information.

6 World Economic Forum, 2018, *The Global Competitiveness Report 2017–2018*. Available from https://www.weforum.org/reports/the-global-competitiveness-report-2017-2018.

Table 2.10: Equivalent ranking of the GCI pillars by income group

		HIGH-INCOME COUNTRIES	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	WORLD AVERAGE	SOUTH AFRICA
ENABLING ENVIRONMENT	Institutions	27	112	98	76	60	69
	Infrastructure	28	121	95	79	78	64
	ICT adoption	32	122	100	72	76	85
	Macroeconomic stability	43	119	88	64	63	57
HUMAN CAPITAL	Health	37	115	103	87	88	125
	Skills	32	118	97	82	78	84
MARKETS	Product market	27	114	98	89	67	74
	Labour market	32	103	93	78	69	55
	Financial system	31	118	87	62	61	18
	Market size	54	112	69	61	65	35
INNOVATION ECOSYSTEM	Business dynamism	33	123	90	73	66	56
	Innovation capability	30	113	81	67	51	46

Source: 2018 GCI (interpreted by NACI)

South Africa's low ranking on human capital (114th) is driven mainly by poor performance in health-related issues. Among the G20 member countries, South Africa is ranked the lowest in respect of health (125th). This low ranking on health is driven mainly by the high incidence of communicable diseases.

3. ENABLERS: PUBLIC SECTOR ACTIVITIES

The government and higher education sectors are important enablers for the current and future innovation performance of a country. Conducive framework conditions provided by government include upgrading the level of human capital and research capacity, STI funding, supportive policies and other relevant support initiatives. Universities are primarily concerned with teaching and research, although more innovative universities are intensively supporting technological innovation and entrepreneurship.

3.1 SCIENCE, TECHNOLOGY AND INNOVATION HUMAN CAPITAL

Various reports and strategies have articulated the human capital challenges within the NSI. The DST's 2017 Science, Technology and Innovation Institutional Landscape (STIIL) review report summarises these challenges as follows:

- High student dropout rates and an insufficient number of graduates at all levels with the right skills, knowledge and aptitude
- Low participation and throughput rates at both undergraduate and postgraduate levels
- An insufficient number of academics and qualified technical support staff (instrument scientists and technical specialists), as well as insufficient infrastructure and equipment to grow postgraduate numbers and enhance research output
- Insufficient collaboration between institutions and sometimes also a lack of trust or willingness to share equipment and human resources
- A significant shortage of qualified schoolteachers in science, mathematics and other scarce disciplines
- Engineering graduates from technical and vocational education and training (TVET) colleges who are inadequately trained and therefore unemployable in industry

This section presents and discusses some of these challenges, including benchmarking against different economies.

3.1.1 Human resources in R&D

Demand-orientated skills planning should start at the point of the deployment of human capital. Table 3.1 illustrates that South Africa needs to triple its number of researchers in order to catch up with upper middle-income countries. At the current rates of investment, this gap will narrow slightly in the long term, but will not reach the numbers that are required.

Table 3.1: Average number of researchers (full-time equivalent) per million inhabitants

	2008	2009	2010	2011	2012	2013	2014	2015	FORECAST 2016	FORECAST 2017	FORECAST 2018
Low-income countries	139	144	150	152	155	157	160	162	167	170	173
Lower middle-income countries	180	184	188	194	206	217	229	238	244	252	261
Upper middle-income countries	813	853	886	939	979	1 018	1 039	1 076	1 122	1 160	1 199
High-income countries	3 648	3 721	3 735	3 825	3 891	3 974	4 076	4 151	4 203	4 276	4 348
South Africa	**192**	**211**	**217**	**246**	**276**	**283**	**307**	**324**	**344**	**364**	**383**

Source: UNESCO's Institute for Statistics; NACI's linear forecast

Table 3.2 illustrates that, in terms of gender, the country is gradually increasing the proportion of female researchers (44.6% in 2016). This is in line with upper middle-income countries, higher than the world average (39.1%) and much higher than that of high-income countries. According to the medium-term outlook, female researchers in South Africa were expected to account for approximately 47.7% of all researchers by 2018. As will be seen in subsequent sections, the country has a relatively large number of female doctoral SET graduates.

Table 3.2: Average percentage of female researchers (full-time equivalent)

	2008	2009	2010	2011	2012	2013	2014	2015	FORECAST		
									2016	2017	2018
Low-income countries	26.5	33.2	22.8	21.5	17.4	18.8	18.5	20.3	15.2	13.7	12.1
Lower middle-income countries	37.3	40.5	33.8	40.1	44.3	44.6	47.7	40.4	46.1	47.2	48.3
Upper middle-income countries	41.6	42.0	41.5	43.2	41.2	42.2	44.7	45.7	45.1	45.6	46.1
High-income countries	37.0	35.5	36.6	34.1	36.4	35.7	36.7	35.4	35.7	35.6	35.5
World average	37.3	37.9	34.9	36.6	38.0	38.2	40.0	38.1	39.1	39.4	39.7
South Africa	**38.4**	**39.0**	**40.9**	**41.7**	**43.4**	**43.5**	**44.1**	**44.4**	**44.6**	**46.8**	**47.7**

Source: UNESCO's Institute for Statistics;NACI's linear forecast

In terms of the racial profile of South African researchers, a large proportion of white researchers remains (50.5% of the total in 2016/17), followed by Africans (33.2%). Overall, these numbers are showing a progressive path towards the transformation of the research workforce as, in the medium term, the proportion of African researchers is expected to grow to 36.6% (see Figure 3.1).

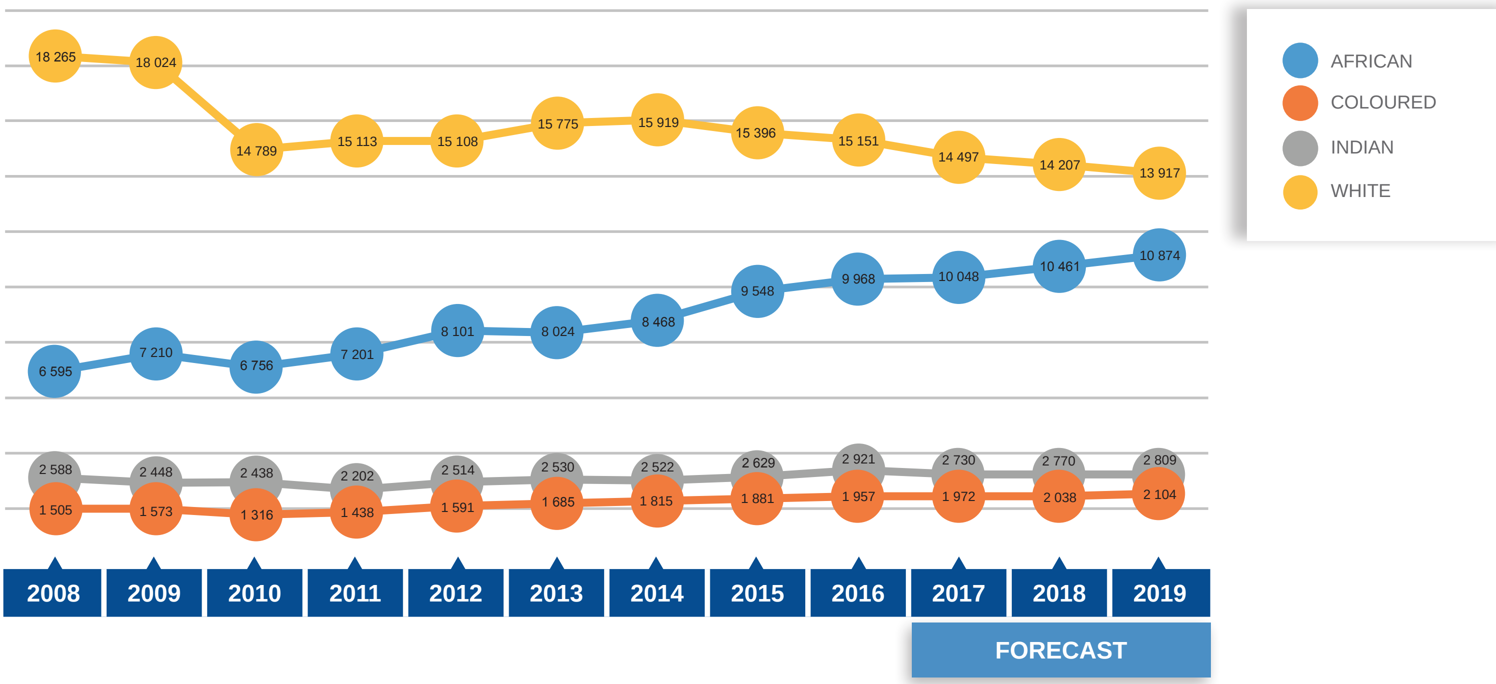


Figure 3.1: Trend in the proportion of South African researchers by race (head count)

Source: National Survey of Research and Experimental Development of the Human Sciences Research Council (HSRC) and DST; NACI's linear forecast

Table 3.3 illustrates the migration of research human resources from the private sector to higher education institutions. Although, in 2008, the proportion of South African researchers based in the business sector was 47.2%, this fell sharply to 36.1% in 2016 and is predicted to decline further to 29.3% by 2019. In contrast, the proportion of researchers based at higher education institutions rose from 27.9% in 2008 to 39.4% in 2016. This is forecast to grow further to 46.1% in 2019.

Table 3.3: Employment of South African researchers by sector (full-time equivalent)

		BUSINESS	HIGHER EDUCATION	SCIENCE COUNCILS	GOVERNMENT	NGOS
2008		6 172	3 644	2 247	805	208
2009		6 060	3 762	2 252	680	188
2010		4 804	3 614	1 777	874	196
2011		4 452	4 355	1 635	1 010	191
2012		4 556	4 701	1 697	1 091	295
2013		4 530	5 001	1 781	924	338
2014		4 636	5 098	1 765	970	396
2015		4 627	4 702	1 827	954	385
2016		4 777	5 220	1 941	969	341
FORECAST	2017	4 112	5 517	1 682	1 052	421
	2018	3 943	5 729	1 643	1 078	449
	2019	3 774	5 941	1 603	1 104	477

Source: National Survey of Research and Experimental Development of the HSRC and DST; NACI's linear forecast

These figures suggest that the business sector is relying increasingly on research from higher education institutions rather than promoting and initiating research internally.

A benchmarking exercise of the deployment of South African researchers by sector of employment (see Table 3.4) shows that a low proportion of researchers in South Africa is employed by the business sector in contrast to the average for upper middle-income countries. In 2015, 43.2% of researchers in upper middle-income countries were employed in the business sector. This is a high proportion in comparison to the corresponding 37.0% for South Africa. Indeed, for high-income countries, a large proportion of the research workforce is in the private sector (57.9%).

Therefore, one can make an argument for South African business enterprises to take on proportionately more researchers themselves or create new businesses that are research intensive. In the absence of such a trend, government instruments such as the Technology and Human Resources for Industry Programme (THRIP) and the Sector Innovation Fund (SIF) have became important in enabling the industrial sectors to fulfil this objective.

Table 3.4: Proportion of researchers by sector of employment (2015)

	HIGHER EDUCATION	BUSINESS	GOVERNMENT	PRIVATE NON-PROFIT	KNOW-HOW
Low-income countries	77.3%	0.3%	22.1%	0.3%	24%
Lower middle-income countries	41.4%	22.0%	34.2%	2.3%	105%
Upper middle-income countries	27.2%	43.2%	29.1%	0.5%	96%
High-income countries	31.9%	57.9%	8.9%	1.3%	79%
World average	32.3%	50.8%	15.6%	1.3%	53%
South Africa	**37.6%**	**37.0%**	**22.3%**	**3.1%**	**86%**

Source: UNESCO's Institute for Statistics

3.1.2 University SET graduations

This section focuses on the supply side of R&D human resources from South African public universities, with a special emphasis on SET qualifications. Table 3.5 illustrates this pipeline from undergraduate diplomas and/or certificates up to doctoral level. Although SET graduations are high as a proportion of all graduations at master's and doctoral levels at 46.4% and 52.0% respectively in 2017, SET graduations are still low at the undergraduate and honours levels.

A very concerning situation exists with regard to postgraduate certificates and diplomas. In 2017, only 7.0% of these qualifications were from SET fields. This figure was down from 27.0% in 2009. This trend might be hugely influenced by the phasing out of qualifications that are not aligned to the 2013 Higher Education Qualifications Sub-framework (HEQSF).

According to the South African Technology Network (SATN), most postgraduate diplomas were not aligned to the HEQSF and, as a result, such qualifications had to be phased out by 2019. It is predicted that, by 2020, only 2.6% of SET graduations will be drawn from postgraduate certificates and diplomas, all other factors being the same. This decline is also taking place at the bachelor degree level.

Table 3.5: Public universities' SET graduation rates

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Undergraduate diploma or certificate	27.2	24.5	22.2	24.1	26.2	27.6	29.3	28.6	27.4	27.0	28.6	29.0	29.5
Bachelor degree	32.3	31.9	32.2	32.4	31.9	31.7	31.5	27.9	26.8	27.7	27.2	26.6	26.0
Bachelor of technology degree	N/A	N/A	N/A	N/A	N/A	N/A	N/A	53.3	49.6	48.5	45.7	43.3	40.9
Postgraduate certificate or diploma	23.3	27.0	25.7	22.1	20.6	16.1	15.5	15.4	9.7	7.0	6.8	4.7	2.6
Honours degree	22.1	22.5	22.1	23.3	24.6	23.9	25.3	25.5	26.9	25.4	26.9	27.5	28.0
Master's degree	40.5	40.4	41.1	42.0	42.2	43.7	43.3	45.7	44.6	46.4	46.7	47.3	48.0
Doctoral degree	48.6	51.0	51.4	54.2	52.4	52.5	50.0	49.9	49.5	52.0	51.1	51.1	51.1
All qualifications	**29.4**	**28.5**	**27.9**	**28.7**	**29.4**	**29.4**	**30.0**	**30.3**	**29.1**	**29.2**	**29.8**	**29.9**	**30.0**

Source: Department of Higher Education and Training; NACI's linear forecast

The relatively high proportion of SET graduates at doctoral and master's degree levels contrasts sharply with the constrained pipeline that is visible at the undergraduate and early postgraduate levels. This can only be possible if there is a large number of non-SET graduates who are not interested in furthering their studies to upper qualifications, or alternatively, if there is an influx of students into the system from other countries.

Indeed, Figure 3.2 illustrates a large number of non-South African SET doctoral graduates (42.2% of all doctoral graduates in 2017). This is a trend that is expected to continue in the medium term. The non-South African doctoral graduates are an important source of human capital for the country's NSI, but only provided they remain within the system upon the successful completion of their studies.

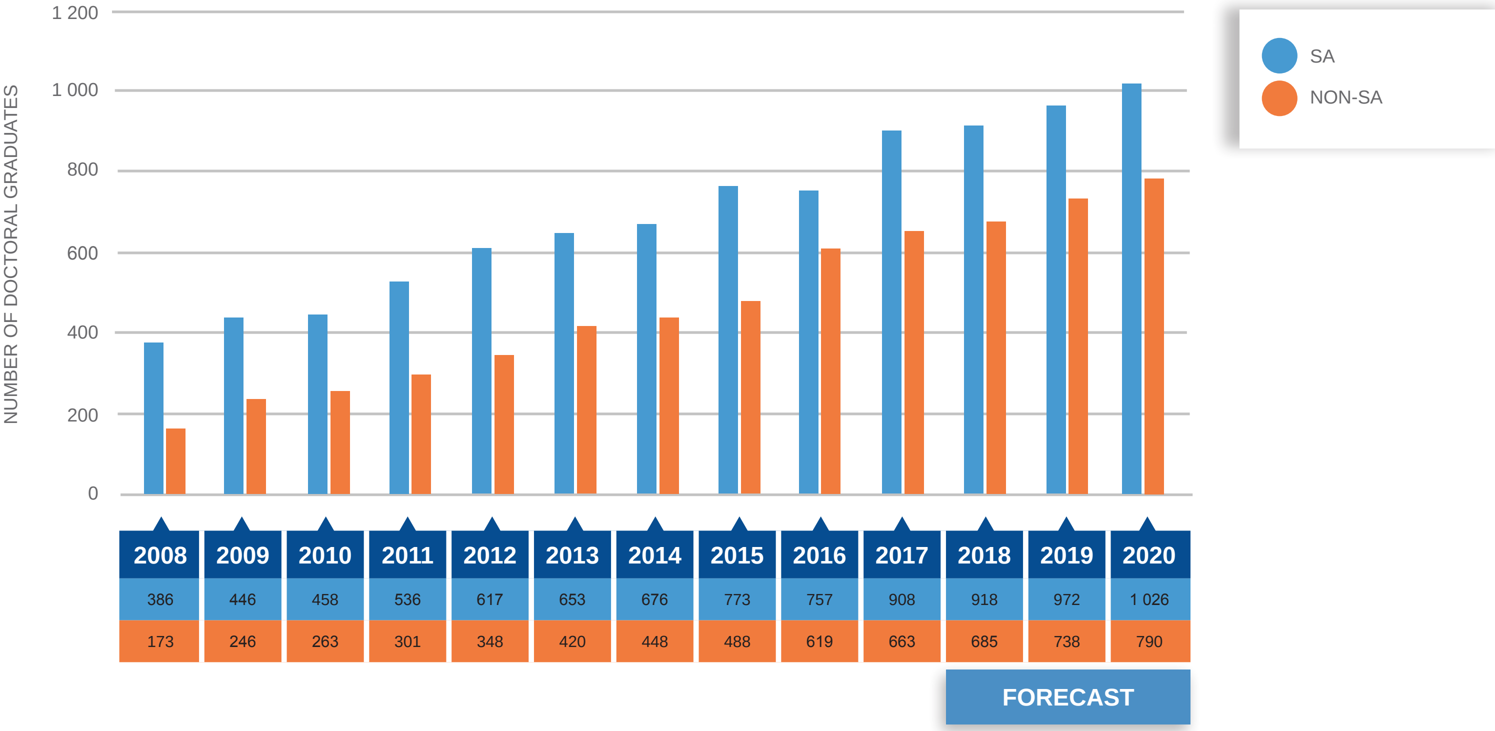


Figure 3.2: Trend in the number of SET doctoral graduates by nationality

Source: Department of Higher Education and Training; NACI's linear forecast

A more detailed profile of gender and nationality for South African SET doctoral graduates is illustrated in Table 3.6.

Table 3.6: Number of SET doctoral degrees awarded by South African universities according to gender and nationality

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
South African total	386	446	458	536	617	653	676	773	757	908	918	972	1 026
South African male	210	226	236	269	307	328	355	367	367	425	437	460	484
South African female	176	221	222	267	310	325	321	406	391	484	481	511	542
SADC total	65	86	90	95	147	151	155	165	199	226	231	248	265
SADC male	52	64	62	74	107	105	104	112	140	160	159	171	182
SADC female	13	23	28	21	40	46	51	53	59	66	72	78	83
Other Africa total	69	99	116	148	149	201	221	252	329	350	352	382	411
Other Africa male	54	89	95	114	113	153	176	199	261	N/A	275	298	321
Other Africa female	15	10	21	34	36	48	45	53	68	N/A	77	84	90
Other foreign total	39	61	57	58	52	68	72	71	91	87	91	96	101
Other foreign male	23	34	36	37	34	41	49	38	51	55	55	58	60
Other foreign female	16	27	21	21	18	27	23	33	40	32	36	38	40

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
No nationality total	16	12	10	17	20	3	6	3	8	18	8	8	7
No nationality male	9	11	10	11	19	3	3	2	7	13	6	6	6
No nationality female	7	1	0	6	1	0	3	1	1	5	2	2	1
Grand total	**575**	**704**	**730**	**854**	**985**	**1 076**	**1 130**	**1 263**	**1 384**	**1 239**	**1 600**	**1 705**	**1 809**
Total males	**348**	**423**	**439**	**505**	**580**	**630**	**687**	**717**	**826**	**652**	**933**	**993**	**1 052**
Total females	**227**	**281**	**292**	**349**	**405**	**446**	**443**	**546**	**559**	**587**	**667**	**712**	**757**

Source: Department of Higher Education and Training; NACI's linear forecast

This disaggregated data reveals some interesting observations that can be useful for SET-related human resource strategies in the country. The first key observation is the fact that more South African females obtain SET-based doctoral degrees than males (484 females as opposed to 425 males in 2017).

A second important observation, which is related to the first one, is the fact that, overall, a higher proportion of males of all nationalities obtain SET-based doctoral degrees than females. This is driven by the fact that few females enter the system from the Southern African Development Community (SADC) and other African countries and do so at a rate that is far lower than their male counterparts.

A benchmarking exercise in Table 3.7 addresses the question of whether South Africa is producing a sufficient number of SET qualifications.

Table 3.7: Higher education qualifications awarded per broad classification (2016)

	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	WORLD AVERAGE	SOUTH AFRICA
Science, engineering and technology	**39.8%**	**31.2%**	**35.5%**	**37.1%**	**35.7%**	**27.3%**
Agriculture, fisheries, forestry and veterinary science	4.8%	2.5%	2.5%	1.3%	2.1%	2.1%
Information and communication technologies	3.6%	4.6%	4.3%	4.5%	4.4%	3.1%
Engineering, manufacturing and construction	11.3%	10.7%	15.2%	13.0%	12.9%	8.3%
Health and welfare	14.9%	7.6%	9.6%	13.4%	11.4%	6.7%
Natural sciences, mathematics and statistics	5.3%	5.8%	4.0%	4.9%	4.9%	7.1%
Business, law and administration	**24.5%**	**28.5%**	**31.4%**	**29.5%**	**29.4%**	**33.2%**
Education	**15.3%**	**14.9%**	**12.9%**	**9.4%**	**12.0%**	**19.4%**
Arts and humanities	**7.6%**	**11.3%**	**6.8%**	**10.0%**	**9.2%**	**4.9%**
Social sciences, journalism and information	**8.7%**	**11.2%**	**8.8%**	**8.9%**	**9.3%**	**14.6%**
Services	**3.3%**	**2.6%**	**3.8%**	**4.8%**	**4.0%**	**0.7%**

Source: UNESCO's Institute for Statistics

It is clear that the current proportion of SET-related qualifications in South Africa, at 29.2% of the total, is not sufficient for the country`s economic growth needs. In fact, it is even lower than that of the low-income countries (39.8% in 2016). A proportion of about 35% (the world average) seems to be ideal. South Africa's higher education qualifications are instead concentrated in the fields of business, administration and law (33.2%) and education (19.4%). The only area of SET in which there is a relatively large proportion of graduates in relation to the world average is in respect of natural sciences, mathematics and statistics (7.1%).

Table 3.8 illustrates that, in line with other economies, the proportion of female SET graduates in South Africa is slightly lower (22.6% in 2016). There is a relatively high concentration of female graduates in the fields of education (24.2%), health and welfare (8.2%) and social sciences, journalism and information (15.5%). This pattern is not unique to South Africa. It is also observed in other countries.

Table 3.8: Higher education qualifications awarded to females per broad classification (2016)

	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	WORLD AVERAGE	SOUTH AFRICA
Science, engineering and technology	**36.7%**	**25.2%**	**29.1%**	**31.9%**	**30.2%**	**22.6%**
Agriculture. fisheries, forestry and veterinary science	5.5%	1.7%	2.1%	1.1%	1.8%	1.7%
Information and communication technologies	3.1%	3.3%	2.6%	2.3%	2.7%	1.9%
Engineering, manufacturing and construction	6.6%	4.9%	7.3%	5.9%	6.1%	4.3%
Health and welfare	17.2%	9.8%	12.7%	17.7%	14.9%	8.2%
Natural sciences, mathematics and statistics	4.3%	5.4%	4.5%	4.8%	4.8%	6.5%
Business, law and administration	**30.3%**	**30.6%**	**30.8%**	**28.7%**	**29.6%**	**31.1%**
Education	**14.3%**	**16.5%**	**16.9%**	**12.9%**	**14.9%**	**24.2%**
Arts and humanities	**7.5%**	**12.9%**	**9.3%**	**11.7%**	**10.9%**	**4.9%**
Social sciences, journalism and information	**8.1%**	**12.6%**	**10.3%**	**10.2%**	**10.5%**	**16.5%**
Services	**2.2%**	**2.0%**	**2.9%**	**4.3%**	**3.3%**	**0.8%**

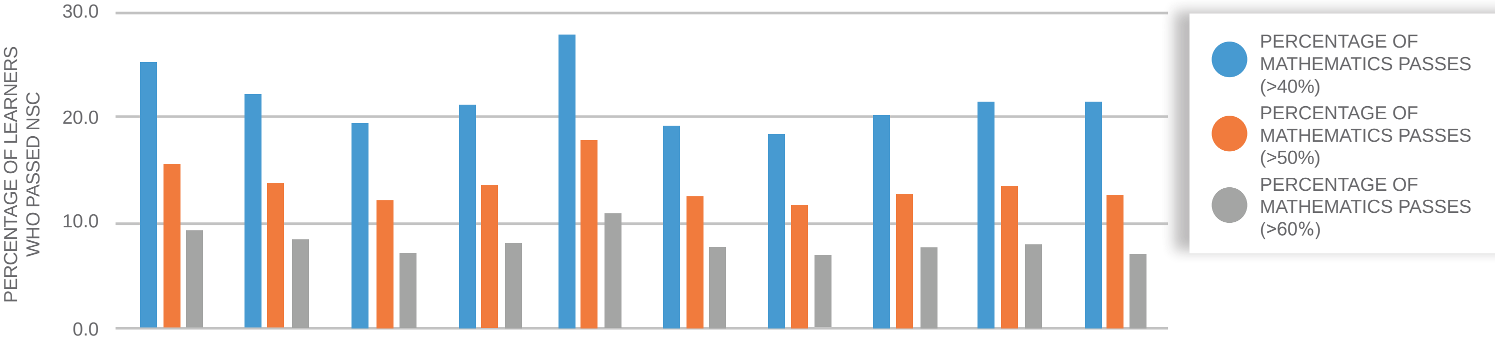
Source: UNESCO's Institute for Statistics

Worldwide, there are certain fields, such as engineering, manufacturing and construction, in which females are not inclined to participate. Although the proportion of females participating in engineering, manufacturing and construction, as a proportion of all SET categories, is 13.0% in high-income countries, only 5.9% of females graduated in these fields in these countries. The advances in technologies such as exoskeletons are expected to narrow this gender gap in future. Central to the Sustainable Development Goals (SDGs) is the aspiration of leaving no-one behind.

3.1.3 Grade 12 Mathematics and Physical Science

The relatively low number of SET graduates at South African higher education institutions with undergraduate qualifications and the identified need to triple the current number of researchers translates into an urgent requirement to strengthen the human capital pipeline from early childhood development to primary and secondary school education. The number of passes in mathematics and physical sciences at the National Senior Certificate (NSC) or Grade 12 level is used in this sub-section as a proxy indicator for the health of the STI human capital pipeline.

As illustrated in Figure 3.3, the biggest increase in the number of learners passing Grade 12 mathematics in 2018 is among those achieving a 40% pass mark. Conversely, there is stagnation at the 60% pass mark. In 2018, 21.7% of learners passed Grade 12 mathematics with at least 40%; 12.7% with a minimum of 50%; and 7.0% with a minimum of 60%. It is worth mentioning that the proportion of mathematics passes at a minimum of 50% declined from 2017 to 2018. A 1% reduction in a minimum pass rate of 60% also took place between 2017 and 2018.

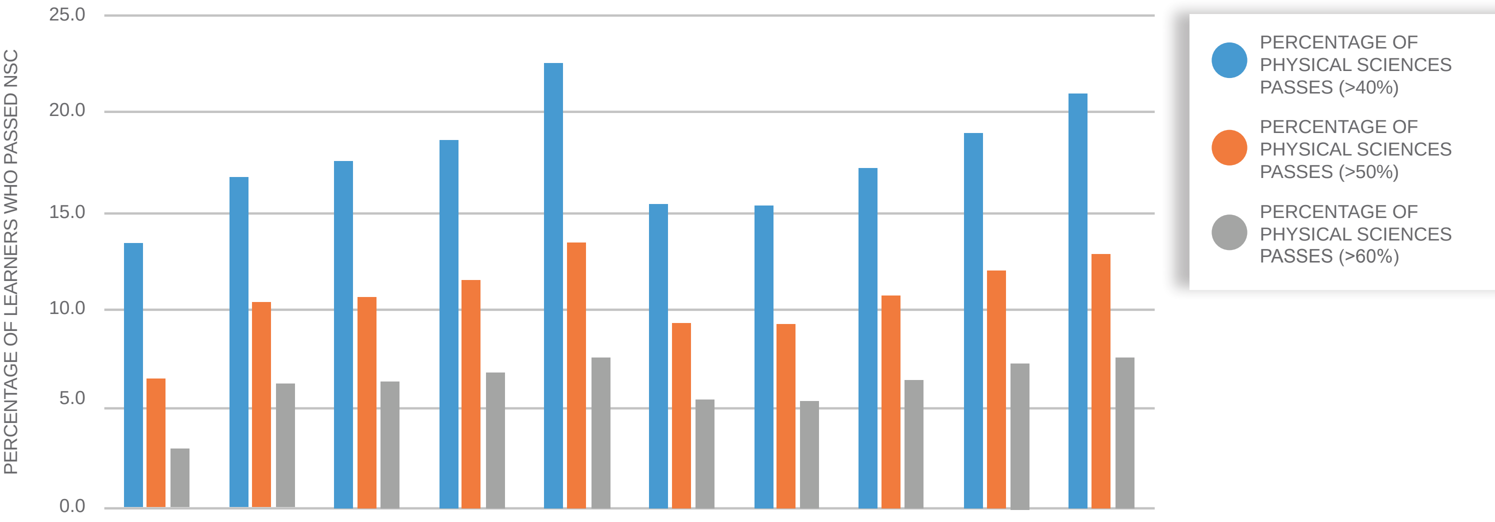


	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Percentage of mathematics passes (>40%)	25.2	22.4	19.4	21.4	28.0	19.6	18.5	20.1	21.4	21.7
Percentage of mathematics passes (>50%)	15.6	13.8	11.9	13.6	18.0	12.5	11.8	12.8	13.5	12.7
Percentage of mathematics passes (>60%)	9.4	8.4	7.1	8.0	10.8	7.6	7.0	7.6	8.0	7.0

Figure 3.3: Trends in the proportion of learners passing NSC mathematics

Source: Department of Basic Education

As illustrated in Figure 3.4, the number of learners passing physical sciences with at least 40% (21.0% in 2018) is nearly the same as that for mathematics (21.7%). This is also observed for minimum pass marks of 50% and 60%, namely 12.8% compared with 12.7% and 7.6% compared with 70% respectively. The major difference is that of a constant increase in physical sciences passes in these three minimum pass rates. In contrast, in the case of mathematics, a decrease in pass marks was observed for those achieving minimum pass marks of 50% and 60%.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Percentage of physical sciences passes (>40%)	13.4	16.7	17.6	18.5	22.5	15.4	15.3	17.2	18.9	21.0
Percentage of physical sciences passes (>50%)	6.6	10.4	10.7	11.5	13.4	9.3	9.3	10.7	12.0	12.8
Percentage of physical sciences passes (>60%)	3.0	6.2	6.3	6.8	7.6	5.5	5.4	6.4	7.3	7.6

Figure 3.4: Trends in the proportion of learners passing NSC physical sciences

Source: Department of Basic Education

In terms of gender, the proportion of female learners passing NSC mathematics with at least 40%, 50% and 60% respectively has been on the rise since 2016 (see Figure 3.5). In 2018, approximately the same number of female and male Grade 12 learners passed NSC mathematics with at least 40%. During the same year, a lower proportion of females passed mathematics with at least 60% and 50% pass levels (45% and 47% of the total respectively).

This constrained pipeline of female learners with a 60% pass rate might partially explain the relatively low proportion of female graduates in fields such as engineering at tertiary level. However, as the figures below suggest, the proportion of females doing well in mathematics and physical sciences is improving. The proportion of female learners relative to males passing NSC physical sciences with at least 40%, 50% or 60% has remained on an increasing trend since 2014.

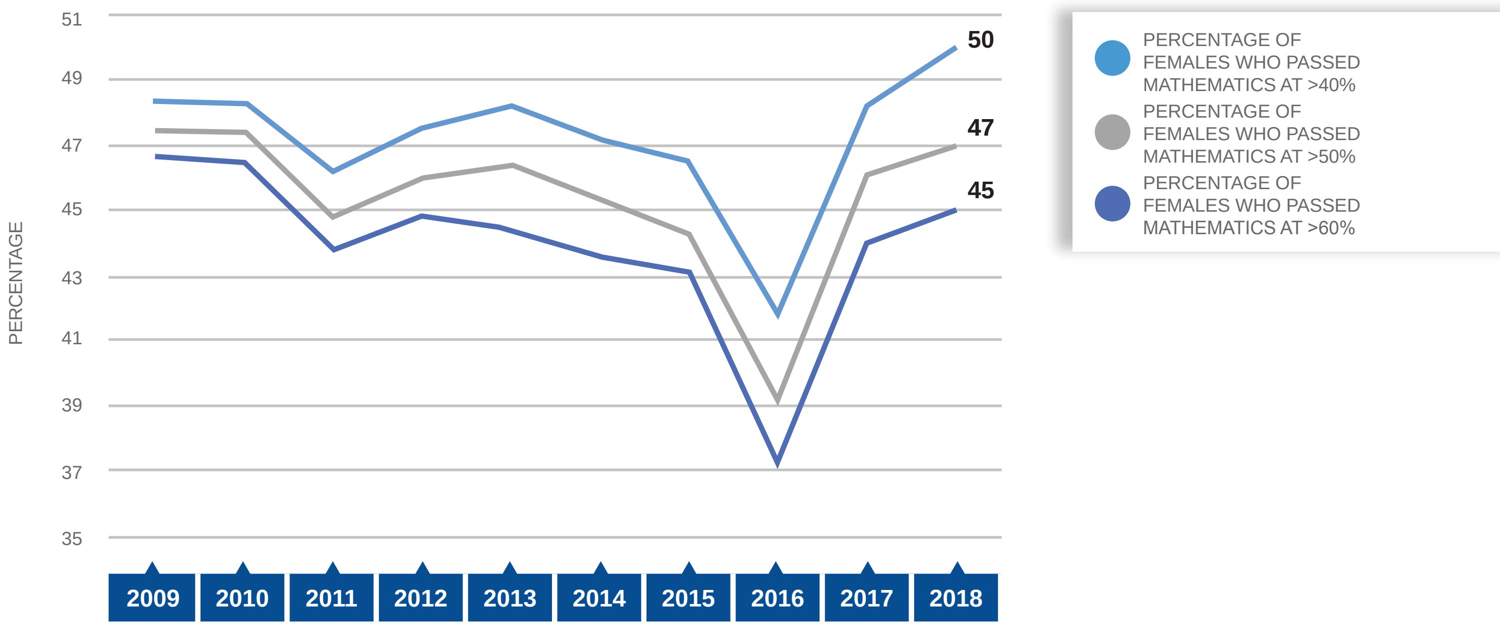


Figure 3.5: Distribution of learners passing NSC mathematics according to gender

Source: Department of Basic Education

While there was a lower proportion of females passing physical sciences with at least 60% (47.1%) during 2018, this proportion was higher, at 52.4%, for a physical science pass mark of 40% and 50% at a pass mark of at least 50%.

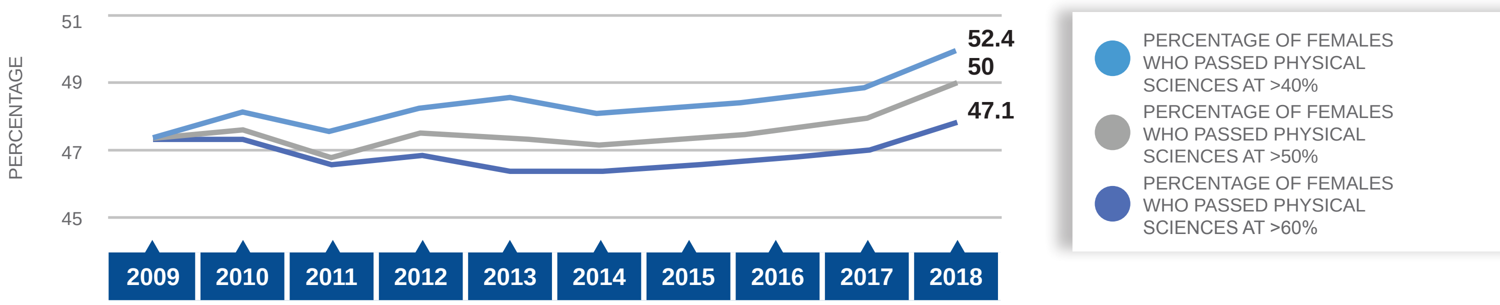


Figure 3.6: Distribution of learners passing NSC physical sciences by gender

Source: Department of Basic Education

3.2 KNOWLEDGE GENERATION

Publications, together with their characteristics (authors' addresses and citations), are arguably the most useful and readily available indicators of STI policy[7] . Figure 3.7 illustrates the number of South African publications during the period 1994 to 2017. The figure shows that there has been a substantial increase since 2005

7 Organisation for Economic Cooperation and Development (OECD), 2016, *Compendium of bibliometric science indicators*, OECD, Paris.

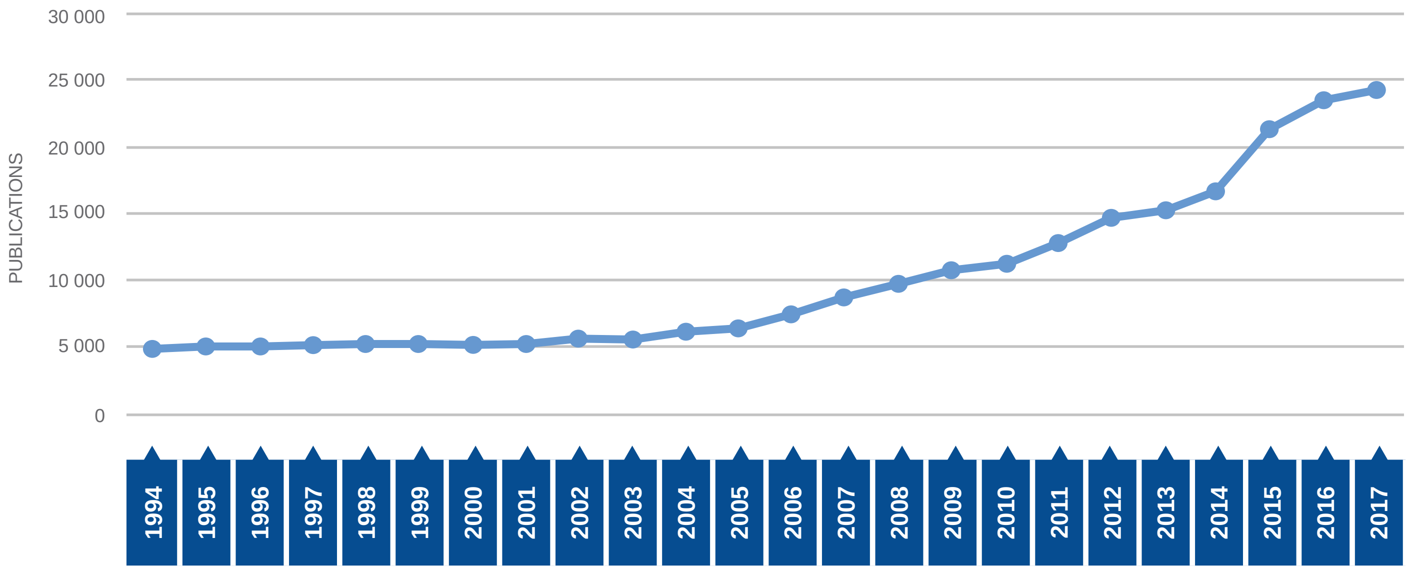


Figure 3.7: Trend of the number of South African scientific publications

Table 3.9 illustrates the growth in annual publications in South Africa since 2008. It should be noted that, during 2015 specifically, there was a substantial increase in the number of South African publications (4 587). Further investigations revealed that, during 2015, the Web of Science (WoS) was expanded to include the journals of the Emerging Sources Citation Index (ESCI).

ESCI is a citation index produced during 2015 by Thomson Reuters, and now by Clarivate Analytics. According to the publisher, the index includes peer-reviewed publications of regional importance and within emerging scientific fields. Around 7 000 journals were selected for coverage at the launch of the index, spanning the full range of subject areas.

The developer mentions that it has been observed that, among the databases produced by Clarivate Analytics, ESCI is the easiest to get into and, as a result, contains many predatory journals. Examples of South African journals included are the *Stellenbosch Theological Journal, South African Family Practice* and *South African Journal of Geomatics.*

Table 3.9: South African publications and annual growth

	ANNUAL NUMBER OF PUBLICATIONS	GROWTH FROM PREVIOUS YEAR
2008	9 660	990
2009	10 736	1 076
2010	11 173	437
2011	12 842	1 669
2012	14 662	1 820
2013	15 259	597
2014	16 739	1 480
2015	21 326	4 587
2016	23 532	2 206
2017	24 158	626

Source: Web of Science

Figure 3.8 illustrates the amended series of South African publications. The ESCI publications were excluded for this time series for the period 2015 to 2017. From a policy perspective, it will be important to monitor the situation to identify changes in funding that affect the country's publication outputs.

An important question is whether there are particular organisations or universities with a proclivity to publish in ESCI journals

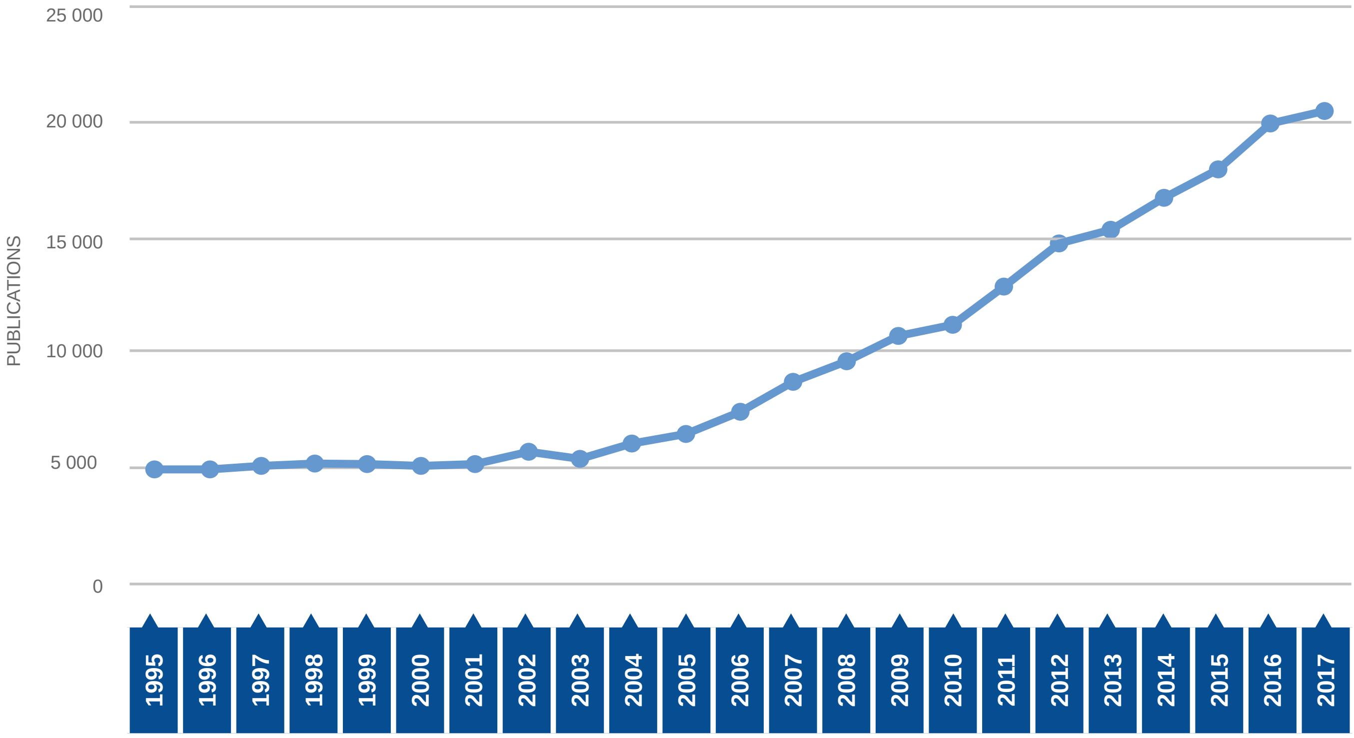


Figure 3.8: Amended South African publications (excluding ESCI)

Table 3.10 illustrates the most prolific organisations publishing in ESCI from 2015 to 2017. The University of KwaZulu-Natal (UKZN) appears at the top of the list, followed by five other universities with very small differences in the number of publications.

Table 3.10: Prolific South African organisations in ESCI (2015–2017)

ORGANISATION	NUMBER OF PUBLICATIONS
University of KwaZulu-Natal	1 161
University of South Africa	1 088
University of Pretoria	1 082
University of the Witwatersrand	1 079
Stellenbosch University	1 046
University of Cape Town	1 039
University of Johannesburg	876
North West University	839
University of Free State	571

Table 3.11 illustrates the most prolific disciplines in which South African authors published between 2015 and 2017. Due to a relatively large number of doctoral graduates in fields such as education, business, law and administration, this pattern of publishing by emerging researchers is not surprising. Religious publications were also prominent, but relatively speaking, scientific publications were low on the list.

Table 3.11: Prolific research areas in ESCI (2015–2017)

RESEARCH AREA	NUMBER OF PUBLICATIONS
Education, educational research	1 132
Business economics	822
Religion	751
Government law	715
Social sciences other topics	470
General internal medicine	451
Health care sciences services	351
Linguistics	289

Table 3.12 illustrates the activity indices of the various research areas of publications from South Africa. The 20 most prolific research areas during the two-year period from 2016 to 2017 were chosen for the identification of the activity indices. The activity indices reveal, to a certain extent, the priority areas manifested in publications and characterise the relative research effort a country devotes to a given subject field.

Its definition is the country's share in the world's publication output in the given field divided by the country's share in the world's publication output in all science fields. An activity index of 1.00 indicates that the country's research effort in a given field corresponds precisely to the world average. An activity index higher than 1.00 reflects a higher than average effort in the field. An index lower than 1.00 indicates a lower than average effort dedicated in the field under investigation.

Table 3.12: Activity indices of South African research areas

RESEARCH AREAS	ACTIVITY INDEX
Infectious diseases	4.76
Religion	3.51
Astronomy and astrophysics	2.98
Plant sciences	2.96
Public environmental occupational health	2.10
Education and educational research	1.94
Environmental sciences and ecology	1.84
Immunology	1.78

RESEARCH AREAS	ACTIVITY INDEX
Government law	1.60
Social sciences and other topics	1.43
Business economics	1.34
Psychology	1.16
General internal medicine	1.12
Mathematics	0.96
Science, technology and other topics	0.94
Physics	0.79
Computer science	0.65
Chemistry	0.65
Engineering	0.63
Materials science	0.50

The above table shows that the highest activity indices are in respect of infectious diseases, religion, astronomy and astrophysics, and plant sciences. The country appears to perform almost five times more research on infectious diseases than is expected by the total research undertaken in the system and the worldwide average. In contrast, the table shows that computer science, chemistry, engineering and materials science have activity indices below 0.65. Unfortunately, the low-index disciplines are precisely those that are mainly supporting the 4IR.

3.3 SCIENCE, TECHNOLOGY AND INNOVATION FUNDING AND SUPPORT

The government's support of STI activities in different sectors can take place in various forms, such as funding, the provision of R&D, technological and innovation infrastructure, the development of human capital, the protection of intellectual property (IP), the coordination of systems of innovation, and the development of policies and regulation. The focus in this section is on government funding of R&D.

3.3.1 Government budget and expenditure on R&D

As part of the NSI coordination, DST annually produces the Scientific and Technological Activities (STA) report. This report collects information about the medium-term government budget allocation on R&D (GBARD), scientific, technical and education training (STET), and scientific and technological services (STS).

In Table 3.13, GBARD is compared with government's estimated funding of R&D in all sectors. As illustrated, since 2010/11 the estimated funding of R&D is consistently lower than that budgeted for a particular year. This trend reversed for the first time in 2016/17, with GBARD at R14 851 million compared with government funding of R&D at R16 428 million. An increase in government funding of R&D is necessary to increase the country's level of R&D to a target of 1.5% as a proportion of GDP, as recommended in the NDP.

Table 3.13: Government budget and funding of R&D

	MILLION RANDS	
	GOVERNMENT BUDGET FOR R&D	GOVERNMENT FUNDING OF R&D
2010/11	15 043	9 019
2011/12	13 313	9 562
2012/13	15 486	10 832
2013/14	11 693	11 007
2014/15	13 963	12 874
2015/16	14 625	14 426
2016/17	14 851	16 428

Source: DST's STA reports; HSRC and DST's National Survey of Research and Experimental Development

Table 3.14 illustrates that government funding of R&D for the higher education sector is on an increase, rising from a share of 45.0% in 2010/11 to 56.1% in 2016/17.

Table 3.14: Government funding of R&D by sector

	MILLION RANDS				
	GOVERNMENT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NOT-FOR-PROFIT
2010/11	990	2 932	3 918	832	38
2011/12	1 112	3 311	4 222	499	41
2012/13	1 269	3 369	4 598	684	114
2013/14	1 436	3 413	5 369	686	103
2014/15	1 712	4 319	6 021	690	131
2015/16	1 426	4 922	7 394	523	162
2016/17	1 531	5 077	9 222	454	144

Source: HSRC and DST's National Survey of Research and Experimental Development

Although, in monetary value, science councils have received a huge increase in government funding of R&D, from R2.9 billion in 2010/11 to R5.1 billion in 2016/17, their share of total R&D funding from government decreased from 33.7% in 2010/11 to 30.9%. A key and dramatic observation is the fact that government funding of R&D performed by the business sector almost halved over the same period.

4. FIRM ACTIVITIES IN SCIENCE, TECHNOLOGY AND INNOVATION

The private sector is an important partner within any system of innovation for the commercialisation of R&D and technological outputs, but also in driving a market-aligned agenda for the prioritisation of research and technology development. This requires a strong feedback loop between the private sector, government and higher education. This chapter analyses the investment patterns of the actors in the private sector, innovation ecosystem linkages and entrepreneurship, and the IP regime.

4.1 INVESTMENTS

The global trends within the STI sector show an under-investment in R&D and human capital in comparison with upper middle-income countries. The aim of this section is to analyse the investment patterns within private business enterprises and to make use of such trends to identify opportunities to unlock investment in R&D, technology and innovation.

4.1.1 Gross fixed capital formation

Private business enterprises remain by far the largest source of direct investment compared with public corporations and government in general (see Table 4.1). Despite a decline in their gross fixed capital formation (GFCF), as a percentage of GDP, from 17.9% in 2008 to 13.4% in 2017, the current investment intensity of private enterprises relative to public authorities and public corporations should remain the same in the medium term, according to the 2020 outlook. The business sector therefore remains critical to attempts to raise the country's R&D expenditure to the level of upper middle-income countries.

Table 4.1: Gross fixed capital formation as a percentage of GDP

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Private business enterprises	17.9	15.2	13.9	14.2	14.1	15.0	15.3	14.9	14.1	13.4	13.8	13.7	13.7
Public corporations	4.4	5.1	4.5	4.3	4.4	4.6	4.3	4.5	4.4	4.3	4.3	4.3	4.3
General government	4.1	3.7	3.1	3.1	3.3	3.5	3.6	4.0	3.8	3.6	3.7	3.7	3.7

Source: SARB's Online Statistical Query; NACI's linear forecast

In terms of the economic sectors, GFCF is in decline within the mining, manufacturing and finance sectors (see Table 4.2) and, in fact, virtually within all sectors of the economy. This is a sad indictment of the economy's longer term potential to grow. Falling GFCF is bound to erode the economy's ability to provide the population's requirements for domestically generated goods and services in the longer term, making the economy even more dependent on imports. GFCF, as a percentage of GDP, is now the largest within the community, social and personal services sector (4.2% of GDP). As the medium-term forecast shows, the electricity, gas and water sector will catch up with this sector in the long term because of the relatively high rate of investment in this sector.

However, as the onset of load shedding in recent times indicates, the increase of investment in the electricity sector has been insufficient and/or poorly designed to provide appropriate energy security. Valuable time was lost during the 1990s and the early part of the 21st century in failing to invest timeously in the sector.

Table 4.2: Gross fixed capital formation by sector as a percentage of GDP

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
Agriculture, forestry and fishing	0.7	0.6	0.5	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
Mining and quarrying	2.8	2.9	2.6	2.6	2.5	2.6	2.6	2.1	1.8	2.0	2.0	1.9	1.9
Manufacturing	4.9	3.4	3.3	3.5	3.3	3.3	3.2	3.2	2.8	2.6	2.7	2.6	2.5
Electricity, gas and water	2.0	2.6	2.4	2.3	2.5	3.2	3.1	3.3	3.5	3.3	3.5	3.6	3.6
Construction	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
Wholesale, retail trade, catering and accommodation	1.7	1.5	1.3	1.4	1.3	1.3	1.5	1.6	1.6	1.5	1.5	1.5	1.5
Transport, storage and communication	3.9	3.7	3.4	3.5	3.8	3.9	3.9	3.8	3.4	3.3	3.5	3.5	3.5
Finance, insurance, real estate and business services	5.7	5.0	4.1	3.8	3.6	3.8	4.0	4.1	4.1	3.7	3.6	3.6	3.5
Community, social and personal services	4.4	4.0	3.5	3.6	3.6	3.8	3.9	4.3	4.2	4.1	4.1	4.1	4.1

Source: SARB's Online Statistical Query; NACI's linear forecast

Table 4.3 illustrates the relatively large increase of the private business enterprises' investments in construction works (civil engineering), all other things remaining equal.

Table 4.3: Percentage distribution of private sector GFCF

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
Residential buildings	15.7	17.3	14.8	13.3	13.3	12.8	13.6	14.5	14.5	15.2	14.0	14.0	13.9
Non-residential buildings	10.7	12.4	12.2	9.9	9.8	8.8	9.5	8.4	8.4	8.0	7.8	7.6	7.4
Construction works	4.1	7.5	6.8	8.7	8.6	11.5	12.2	10.8	11.1	11.9	12.8	13.2	13.5
Transport equipment	12.2	9.5	10.8	12.1	12.0	12.0	11.5	11.5	12.1	11.0	11.7	11.7	11.7
Machinery and other equipment	45.5	41.2	42.7	44.1	43.4	41.5	39.5	40.7	39.8	40.0	39.4	39.1	38.9
Other	11.8	12.2	12.6	11.7	12.7	13.3	13.6	14.1	14.0	14.0	14.3	14.5	14.6

Source: SARB's Online Statistical Query; NACI's linear forecast

This type of investment will catch up with that of investment in residential buildings by 2020. The driving factor is probably Eskom's new build programme, especially the construction of the giant Medupi and Kusile power stations, which aims to expand power generation and transmission capacity. The construction of the Gautrain and other projects in preparation for the 2010 International Football Federation (FIFA) World Cup also contributed to a rising trend of investment by the private sector from 2008 to 2010.

4.1.2 R&D expenditure and funding in the business sector

As shown by the previous R&D surveys, a significant portion of business sector capital expenditure on R&D goes towards vehicles, plant, machinery and equipment. One would therefore expect BERD to have been constrained in line with the declining trend of the private sector's fixed capital formation. As illustrated in Figure 4.1, BERD, as a proportion of GFCF within the private sector, has been decreasing continuously over the past decade.

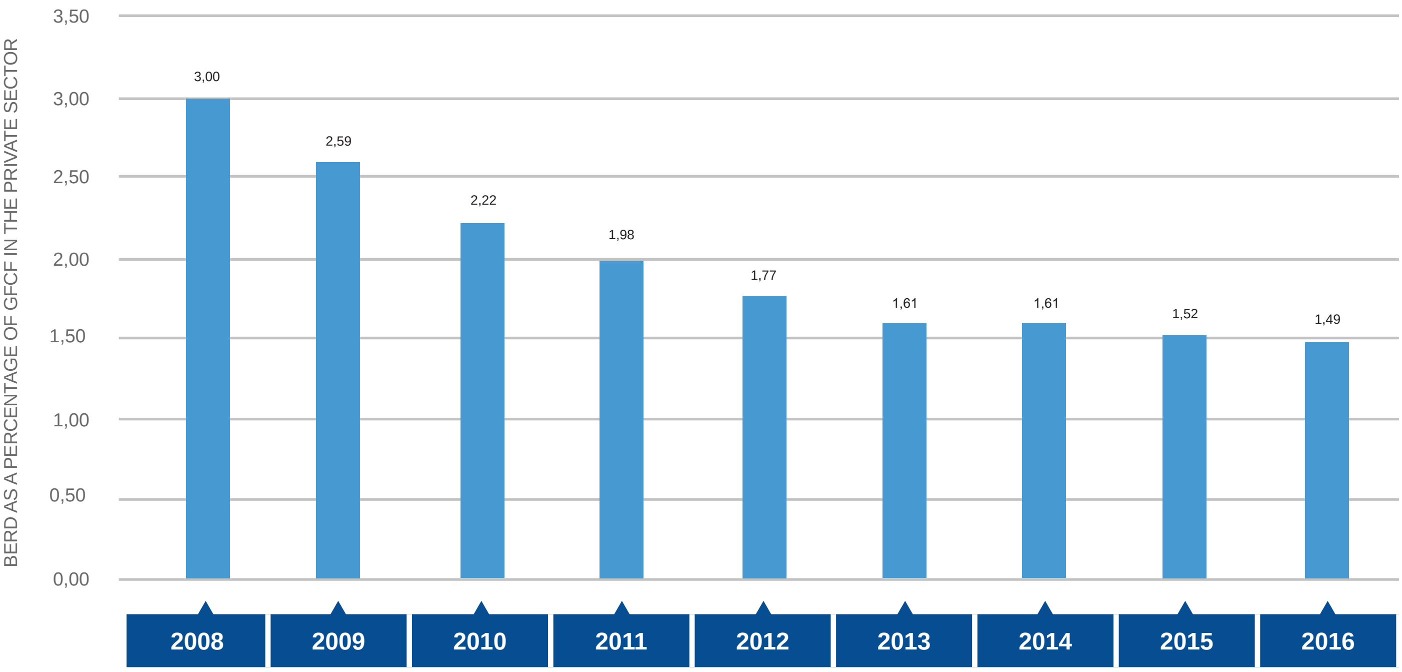


Figure 4.1: BERD as a percentage of GFCF within the private sector

As a result, BERD, as a percentage of GERD, is low in South Africa when compared to a selected list of upper middle-income countries. In 2016, China had a BERD proportion of 77.46%, whereas that of South Africa was just 41.41%. On average, for the same year, the upper middle-income countries, with available data, had an average BERD, as a proportion of GDP, of 52.11%, up from 46.36% in 2009. This contrasts starkly with the corresponding decline in South Africa's BERD, as a percentage of GERD, from 58.61% in 2008 to 41.41% in 2016. Without a doubt, it is possible to conclude that the country's R&D intensity within the business sector has been declining conspicuously and is considerably lower than it ought to be to help sustain higher longer-term economic growth and prosperity.

Table 4.4: BERD as a percentage of GERD in upper middle-income countries

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Belarus	54.07	56.39	60.67	69.87	69.10	65.32	61.92	65.62	66.84
Botswana	-	-	-	-	10.71	17.68	-	-	-
China	73.26	73.23	73.42	75.74	76.15	76.61	77.30	76.79	77.46
Colombia	30.02	21.77	23.80	24.31	31.72	23.92	43.91	46.36	49.17
Ecuador	8.53	40.85	43.40	58.12	57.25	49.06	42.30	-	-

	2008	2009	2010	2011	2012	2013	2014	2015	2016
Malaysia	70.49	69.86	64.99	56.67	64.45	-	45.66	51.95	.-
Mexico	34.06	36.66	35.24	34.89	29.69	31.23	29.94	29.97	30.55
Montenegro	-	-	-	28.65	-	49.31	38.53	30.53	-
Romania	29.96	40.18	38.32	36.05	38.97	30.66	41.45	44.00	55.19
Russia	62.91	62.38	60.51	60.96	58.34	60.60	59.61	59.21	58.71
Serbia	9.08	14.32	11.63	9.38	24.97	13.27	29.65	31.73	37.52
South Africa	58.61	53.16	49.66	47.12	44.28	45.92	45.29	42.72	41.41
Thailand	-	41.21	-	50.61	-	-	54.25	70.20	-
Average	**43.10**	**46.36**	**46.16**	**46.03**	**45.97**	**42.14**	**47.48**	**49.92**	**52.11**

Source: UNESCO's Institute for Statistics

This market failure of relatively low business investment in R&D typically calls for government intervention in the form of direct and indirect incentives and through other forms of non-financial support. More generally, the political and economic environment for investment has proved unattractive for private businesses to commit to large projects that might boost the country's longer-term productive capacity. However, government too has been delinquent in its responsibilities to assist the business sector.

As illustrated in Table 4.5, in 2015, government funded only 3.78% of BERD, down from 20.82% in 2008. As a developmental state, this level of funding is exceedingly low in comparison with the 21.84% average value for select upper middle-income countries and 6.39% for high-income countries.

Table 4.5: Benchmarking of BERD financed by government

	2008	2009	2010	2011	2012	2013	2014	2015
High-income countries (36)	6.05	7.44	8.23	7.34	6.85	6.98	6.77	6.39
Upper middle-income countries	23.66	21.25	20.98	17.35	19.93	21.41	22.68	21.84
China	4.30	4.33	4.57	4.38	4.63	4.51	4.20	4.26
Mexico	12.09	17.16	8.39	9.23	19.07	34.07	36.08	35.31
Romania	39.15	20.66	30.06	18.14	19.57	14.03	19.01	13.66
Russia	56.04	57.37	64.18	58.67	60.44	61.48	62.67	63.41
South Africa	20.82	12.84	8.27	4.77	6.47	5.82	5.19	3.78
Turkey	9.54	15.16	10.42	8.91	9.41	8.57	8.92	10.62
Upper middle-income countries (excluding Russia)	17.18	14.03	12.34	9.09	11.83	13.40	14.68	13.53

Source: OECD's Main Science and Technology Indicators

Among these upper middle-income countries, government finances most of the R&D. In Russia for example, government provided 63.41% of funding for R&D by the business sector in 2015. Mexico's government has also been increasing its investment in BERD. In 2017, Russia ranked 45th on the GII, whereas Mexico and South Africa ranked 58th and 57th respectively.

The system of innovation in Russia is characterised by government's central model of managing all spheres of activity. According to the OECD's 2008 country review of Mexico's national system of innovation, the science and technology laws of 1999 and 2002, together with other related regulations, introduced favourable institutional changes to improve interaction between the innovation system actors and greater coordination between decision-making instances.

Indeed, this improved coordination in Mexico resulted in a significant increase in government funding of BERD from 12.09% in 2008 to 35.31% in 2015. South Africa needs such improved NSI coordination to increase its level of R&D expenditure, especially in the business sector. Table 4.6 illustrates the trend in the disbursements of government's innovation-related grants to the private sector.

Table 4.6: Disbursements of innovation-related grants to the private sector

	MILLION RANDS				
	2013/14	2014/15	2015/16	2016/17	2017/18
R&D Tax Incentive	199	104	216	-	-
Small Enterprise Development Agency (SEDA) Technology Programme	119	126	132	139	146
Support Programme for Industrial Innovation	75	-	21	21	36
Technology and Human Resources for Industry Programme	147	156	148	2	34
Cluster Development Programme	-	-	-	-	23
Incubator Support Programme	-	-	-	-	107
Manufacturing Competitiveness Enhancement Programme	991	1 820	1 114	1 115	490

Source: National Treasury Budget Review; various annual reports

These instruments are not complete due to the non-uniform ways of reporting. There is therefore a need to develop and establish a comprehensive monitoring and evaluation framework. Most innovation support instruments are based either at the dti or DST.

4.2 INNOVATION LINKAGES AND ENTREPRENEURSHIP

The complex nature of innovation highlights the importance of linkages among various actors from the government, private sector, higher education and civil society. These linkages can be formal or informal; and they can take place at the individual or corporate level. This sub-section is inclined more towards formal and corporate collaborations or linkages.

4.2.1 Innovation patterns of technology: Top 100 companies

The Technology Top 100 (TT100) Business Innovation Awards programme, run by The Da Vinci Institute, is one of South Africa's premier awards programmes. Based on over 150 metrics, the programme provides a deep insight into the "true" sustainability of organisations. Emphasis is placed on how the organisation manages technology, innovation and people within a systemic context. This is referred to as the Technology, Innovation, People and System (TIPS) framework.

Management of technology

Under the TIPS framework, the management of technology is all about the strategic tools and metrics organisations use to gain a competitive advantage. Such tools include the technology roadmaps, which are used by 93.10% of the entrants of 2018 TT100 (see Table B1 in Appendix B). Other technology management tools these organisations use for decision making include S-curves and stage gate processes (both comprise 45.95% of the TT100 entrants).

The dominant use of technology roadmaps is encouraging as these future technology planning tools are useful for long-term technology planning. This shows that the majority of TT100 organisations is inclined towards a long-term competitive strategy as opposed to short-term gains.

Approximately 78.38% of TT100 organisations had a technology management strategy in place, while 32.43% of these organisations sourced technology from abroad. Technology transfer, from advanced economies and other peer countries in the Global South, is necessary for technological catch-up and leapfrogging.

Management of innovation

The TIPS framework defines management of innovation as a concept that determines how organisations stimulate and capitalise on the ideation process to develop an innovative product or service, which has either a commercial or a social value.

As illustrated in Table B2 in Appendix B, more than 81% of TT100 organisations have an innovation management strategy in place, as assessed during 2018. All these organisations are also involved with product innovation (100%), while service innovation is also dominant (93.10%), followed by process innovation (82.76%). Process innovation is associated with improvements to or the addition of new capacity in terms of production infrastructure.

A strong emphasis on product innovation reveals the characteristics of TT100 companies and one would expect them to be concentrated more in manufacturing, with services that support the products being sold to the market. Process innovation can also be a good source of revenue if the know-how is sold to other companies for manufacturing their products.

Only 65.52% of these TT100 organisations were innovating in the area of people management. Within the context of a knowledge-driven economy, human capital becomes a vital source of competitive advantage, hence there is a need to constantly innovate around this important area of people innovation.

Management of people

A relatively low focus on the management of people is further confirmed by an observation that, in 2018, only 45.94% of TT100 organisations had a people management strategy in place (see Table B3 in Appendix B). Even those organisations that had a strategy in place seemed to be divergent in their approaches (the retention of skilled employees and the degree of control employees have over their conditions of employment).

According to the TIPS framework, people management is about the processes that organisations deploy in the development of their human capital, and how they retain and reskill existing employees, how they incentivise their people and how they plan for succession to ensure organisational longevity.

Systemic thinking

The above three components of the TIPS framework focus on internal technology, innovation and people management issues and strategies. At a systemic level, the management of systems is the process of synthesis, where the systemic integration of all organisational activities and performance is used to solve unique problems, and where a hyper-competitive redesign of the landscape occurs. This includes internal synovation and organisational ecology that allows the parts to become greater than the whole.

As illustrated in Table B4 in Appendix B, approximately 51.35% of TT100 organisations integrate innovation, people and technology activities and practices. In terms of the interface with the innovation ecosystem, 68.42% of organisations said they collaborate with key competitors and government on common issues facing their industry. The same percentage of organisations (68.42%) reported that they meet with government agencies in an attempt to improve the competitive positioning of their organisations and/or the industry. This systemic collaboration is encouraging as it steers the system of innovation in a more focused, mutually beneficial direction. As illustrated in Table B4 in Appendix B, only 31.25% of TT100 organisations are said to be impacted on negatively by government policy.

Another form of collaboration is the outsourcing of R&D activities to other organisations within the innovation ecosystem. This is the case, as only 10.81 TT100 organisations had a dedicated R&D department and only 32.43% of them had R&D facilities located on the same premises as those on which they conduct their normal business operations. One of the challenges that results from collaborations at the systemic level is intellectual property (IP) infringement. Only 52.63% of TT100 organisations have an IP management strategy in place and only 42.11% are using patent registration to protect their IP.

4.3 INTELLECTUAL PROPERTY RIGHTS REGIME: PATENTS

Patents are used internationally as indicators of national and corporate inventive activity. In the same way that scientific articles are accepted as a legitimate reflection of scientific research, patents are accepted as a reflection of technological achievements. It has been pointed out that “patent statistics remain a unique source for the analysis of the process of technical change. Nothing else even comes close in the quantity of available data, accessibility, and potential industrial, organisational, and technological detail”[8].

Patents fulfil two roles. They provide inventors with legal protection for novel products and processes and, simultaneously, ensure that knowledge of these products and processes becomes available to society. In this way, both private and public interests are served. The concept of a patent is described as follows:

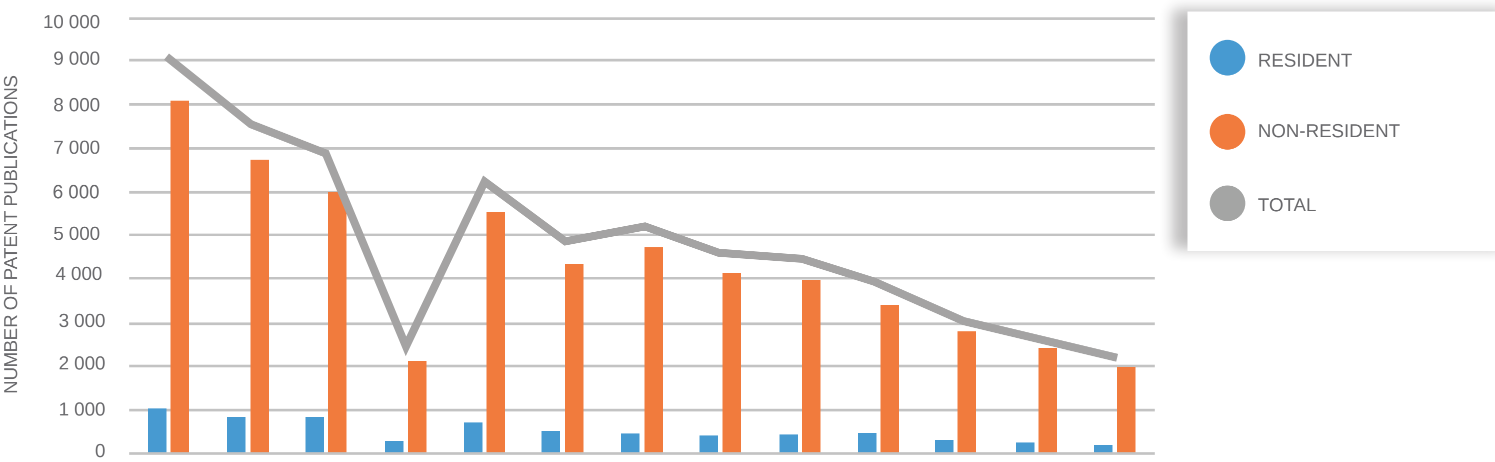
“A patent is an exclusionary right granted by a government entity. The concept behind the United States patent system is that the government grants statutory protection to an inventor in the form of exclusionary rights for a period of years in return for a disclosure of the creativity of the grantee. The exclusionary rights granted by the patent are the rights to exclude others from making, using or selling the patented invention throughout the United States and its territories for a period of 17 years. In exchange for these rights, the patent discloses and teaches technical knowledge relating to the invention.

“During the life of the patent, scientists and other inventors benefit from the disclosure of prior art information by avoiding repeating efforts to discover that which is already known. After the patent expires, the invention belongs to the public and anyone can make, use or sell the invention without permission of the patentee”[9] .

Patent analysis possesses a number of strengths that facilitate their universal use as scientometric tools. They are highly reliable because they are well defined and unambiguous. They facilitate detailed categorisation and hence make the study of scientific and technological fields and sub-fields possible. Finally, they make international comparisons possible.

As illustrated in Figure 4.2, the production of South African patents is declining. This is a trend that is set to continue beyond 2020. The low level of inventions in South Africa is a serious policy issue that needs urgent attention. An incentive regime is a possible solution. Since the closure of the Innovation Fund, the only tangible instrument available for this purpose is the Intellectual Property Rights Act (Act No. 51 of 2008). Through this Act, the National Intellectual Property Management Office (NIPMO) is required to provide incentives to recipients and their IP creators to reward them for proactively securing IP protection and commercialising it for the general purpose of innovation.

Such incentives can make up to 30% of institutions’ revenue accruing from such IP. Patents might sometimes compete with publications, and a balanced portfolio is ideal.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Non-resident	8 087	6 755	5 994	2 095	5 527	4 376	4 737	4 159	4 016	3 405	2 791	2 405	2 019
Resident	1 014	835	855	262	710	497	462	422	427	481	282	255	168

FORECAST

Figure 4.2: South African residents’ and non-residents’ patent publications

Source: WIPO’s IP Statistics Data Centre; NACI’s linear forecast

8 Griliches, Z., 1990, Patent statistics as economic indicators: A survey, *Journal of Economic Literature*, 28:1661–1707.
9 Carr, K.F., 1995, *Patents handbook: A guide for inventors and researchers to searching patent documents and preparing and making an application,* McFarland and Co., Jefferson, NC and London.

Figure 4.2 further illustrates that the lion's share (87.6%) of patent publications relates to non-residents, a trend that will continue beyond the medium-term outlook. In contrast, Table 4.7 illustrates that, for the upper middle-income countries as a whole, residents' share of patents was high at 83.9% in 2017. The highest level of indigenous technologies in these countries is found in food chemistry (89.8%), machine tools (85.5%), materials and metallurgy (84.7%) and environmental technology (84.6%).

In South Africa, given the fact that residents' patents are relatively low, the incidence of indigenous technologies is slightly higher in respect of fields such as civil engineering (34.0% in 2017), information technology (IT) methods for management (26.8%), other consumer goods (25.4%), mechanical elements (25.2%), transport (24.4%) and control systems (24.2%).

Table 4.7: Proportion of residents' patent publications by technology per income group (2017)

TECHNOLOGY	LOW-INCOME	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	SOUTH AFRICA
Unknown	2.4	19.3	42.8	65.3	11.4
Electrical machinery, apparatus, energy	0.8	40.7	71.6	62.4	19.3
Audio-visual technology	0.0	20.3	57.2	58.6	20.1
Telecommunications	3.1	29.7	68.8	59.5	13.2
Digital communication	0.6	9.5	73.2	50.9	4.7
Basic communication processes	0.0	53.0	60.0	54.6	15.9
Computer technology	2.4	38.0	73.1	59.1	14.8
IT methods for management	5.1	37.5	80.6	75.1	26.8
Semiconductors	0.0	34.3	51.2	56.3	8.3
Optics	0.0	28.9	52.6	61.8	7.4
Measurement	1.1	62.1	83.3	62.6	11.3
Analysis of biological materials	0.0	48.2	73.5	50.2	9.4
Control	3.3	49.4	83.4	67.9	24.2
Medical technology	4.4	42.0	60.4	54.2	7.1
Organic fine chemistry	0.7	13.0	59.7	41.8	1.1
Biotechnology	0.5	17.4	67.7	43.8	2.9
Pharmaceuticals	1.3	15.0	68.2	36.2	1.6
Macromolecular chemistry, polymers	3.0	19.9	72.6	51.8	3.1
Food chemistry	1.1	46.6	89.8	65.2	4.9
Basic materials chemistry	0.8	19.8	77.8	50.7	4.9
Materials and metallurgy	0.5	42.3	84.7	60.4	7.5
Surface technology, coating	0.0	37.2	74.5	57.2	5.9
Micro-structural and nano-technology	0.0	68.4	82.2	59.8	6.7
Chemical engineering	0.3	41.3	80.4	59.5	10.1
Environmental technology	0.0	43.2	84.6	67.7	15.6
Handling	0.8	20.3	75.4	68.4	18.7
Machine tools	0.0	45.2	85.5	65.5	13.1
Engines, pumps and turbines	0.5	47.0	60.8	62.6	10.9
Textile and paper machines	2.1	23.9	73.5	65.1	6.4
Other special machines	1.1	51.9	83.2	67.6	16.3

TECHNOLOGY	LOW-INCOME	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	SOUTH AFRICA
Thermal processes and apparatus	0.9	41.9	81.9	72.3	20.0
Mechanical elements	2.8	37.7	70.2	65.7	25.2
Transport	0.0	42.3	62.9	69.4	24.4
Furniture, games	2.4	38.4	77.7	78.8	22.1
Other consumer goods	1.4	21.5	75.1	70.2	25.4
Civil engineering	0.0	41.2	83.1	74.3	34.0
All technologies	**0.0**	**28.8**	**83.9**	**61.7**	**12.4**

Source: WIPO's IP Statistics Data Centre

South African patents in the USPTO

Figure 4.3 illustrates the number of patents awarded to South African inventors in the USPTO during between 2000 and 2018. The figure shows the number of utility patents granted to South African inventors by calendar year of grant. Patent origin is determined by the residence of the first named inventor.

The figure shows that the number of South African patents in the USPTO decreased between 2000 and 2007, after which an increase occurred between 2007 and 2016. During 2018, the number of registered patents exhibited a decline.

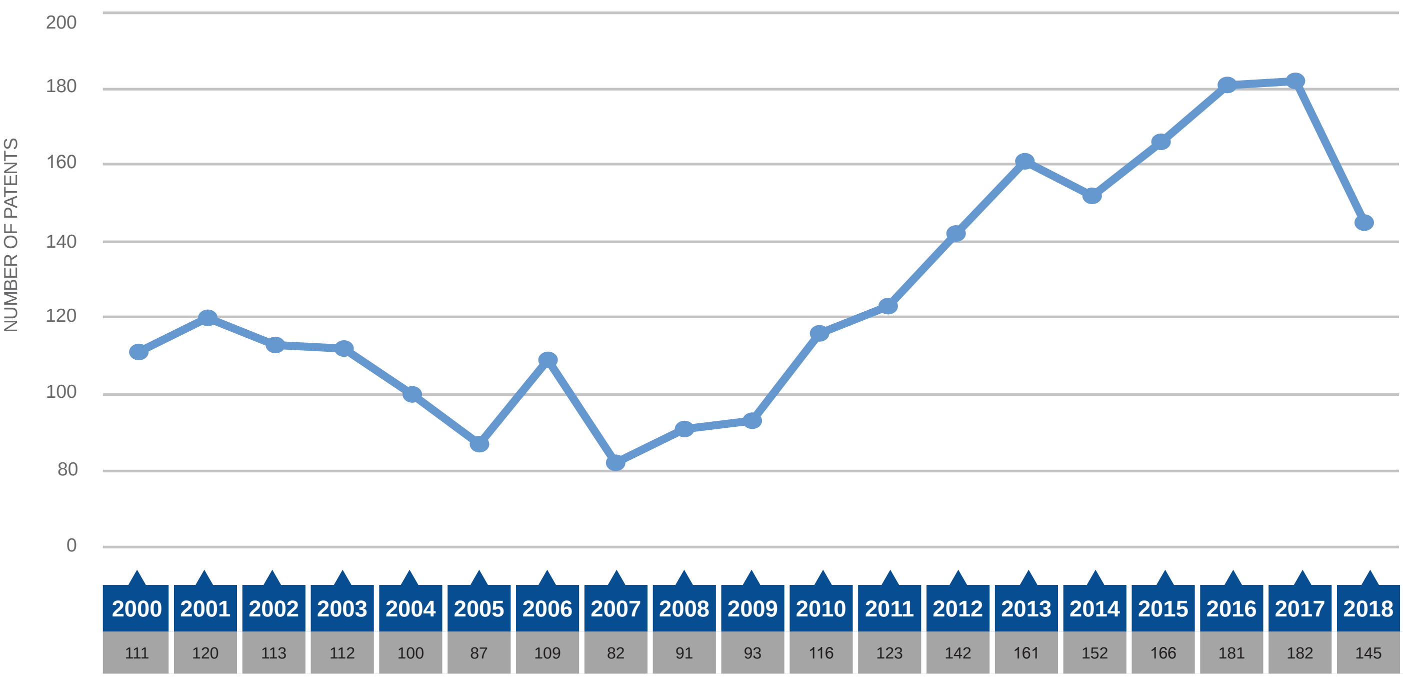


Figure 4.3: South African patents registered at the USPTO

Table 4.8 shows the most prolific organisations in terms of patents in South Africa between 2011 and 2018. Amazon Technologies appears on top of the list (99 patents), followed by Sasol Technology (99 patents), CSIR (38 patents), Element Six Abrasives South Africa (31 patents) and the University of the Witwatersrand (31 patents).

It should be emphasised that there are 211 individually owned patents in the list.

Table 4.8: Patent grants by organisation (2011–2018)

ORGANISATION	NUMBER OF PATENTS
Individually owned patent	211
Amazon Technologies, Inc.	99
Sasol Technology (Pty) Ltd	68
CSIR	38
Element Six Abrasives SA	31
University of the Witwatersrand	31
University of Cape Town	27
Stellenbosch University	27
Detnet South Africa (Pty) Ltd	22
Spinalmotion, Inc.	20
Joy Mm Delaware, Inc.	16
North West University	16
Simplify Medical (Pty) Ltd	16
Cork Group Trading Ltd	15
INSiAVA (Pty) Ltd	12
Oracle International Corporation	12
Visa International Service Association	11
Azoteq (Pty) Ltd	11
Discovery Holdings Ltd	11
South Africa Nuclear Energy Corporation Ltd.	9

Table 4.9 shows the number of patents granted to South African universities and science councils over the period per calendar year.

Table 4.9: Number of patents granted to universities and science councils

ASSIGNEE	2011	2012	2013	2014	2015	2016	2017	2018	TOTAL
CSIR	4	2	5	1	11	4	7	4	38
University of the Witwatersrand	2	4	4	4	8	6	1	2	31
University of Cape Town	3	1	7	3	1	3	3	6	27
Stellenbosch University	0	0	1	2	2	6	6	10	27
North West University	1	3	3	1	3	1	2	2	16
University of Pretoria	0	0	1	0	1	2	2	1	7
University of the Free State	0	0	1	2	0	1	0	3	7
University of KwaZulu-Natal	0	1	0	1	1	3	0	0	6
Tshwane University of Technology	0	1	1	1	0	2	0	0	5
South African Medical Research Council	0	0	2	0	1	0	0	0	3
Mintek	0	0	0	0	0	0	1	1	2
University of Johannesburg	0	0	0	1	0	0	1	0	2
University of South Africa	0	0	0	0	0	0	0	1	1
Agricultural Research Council	0	1	0	0	0	0	0	0	1

The CSIR appears at the top of the list with 38 patent grants, followed by the University of the Witwatersrand, the University of Cape Town, Stellenbosch University and North West University.

5. INNOVATION OUTPUTS

Due to the complex nature of innovation, there is no standard optimal pathway that is suitable for success in the innovation process at a firm, sectoral, local or country level. Similarly, it is difficult to attribute success in innovation to specific individual or organisational contributions as a complex system is characterised by the inability of a single actor to coordinate other actors. The contribution to the socioeconomic innovation output components discussed below is therefore from different sectors, organisations and individuals who, together, form the NSI.

5.1 INNOVATION FOR ECONOMIC IMPACT

This section assesses the contribution of the country`s manufacturers' exports according to the technological intensity of their products. This type of analysis shows the extent to which the country is transforming towards a knowledge-driven economy in the same way as high-income countries are. In addition, the value added per sector shows the change in structure of the South African economy and its benchmarking with the income groups of different countries.

5.1.1 Gross value added by sector

The South African economy is increasingly becoming service-based (see Table 5.1), mainly due to it being driven by growth in the financial services sector, but also due to the country's continued deindustrialisation. Both the primary and industrial sectors are on a declining trend. This pattern is expected to continue in the medium term.

The manufacturing sector's value add is expected to reach 11.78% of GDP by 2019, which is down from 13.34% in 2016. In contrast, the mining and utility sectors will see a rise in their shares from 11.61% in 2016 to 12.40% in 2019. This is not surprising as there has been a huge increase in GFCF within the electricity, gas and water sectors over the past decade.

While this conclusion might be theoretically valid, recent problems with electricity generation at Eskom's recently built power stations raise some doubts about the likely increase in the importance of the utility sector.

Table 5.1: Proportion of South African value added by economic activity

										FORECAST		
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture, hunting, forestry and fishing	**3.17**	**2.99**	**2.63**	**2.54**	**2.41**	**2.33**	**2.43**	**2.32**	**2.43**	**2.12**	**2.03**	**1.93**
Industry	**31.35**	**30.38**	**30.16**	**29.90**	**29.60**	**29.65**	**29.56**	**29.15**	**28.93**	**28.62**	**28.37**	**28.12**
Mining and utilities	11.02	11.17	11.96	12.78	12.72	12.71	12.04	11.62	11.61	12.28	12.34	12.40
Manufacturing	15.99	15.00	14.38	13.31	13.00	12.90	13.41	13.39	13.34	12.38	12.08	11.78
Construction	4.35	4.20	3.83	3.81	3.88	4.04	4.11	4.15	3.98	3.97	3.95	3.94
Services	**65.48**	**66.64**	**67.21**	**67.56**	**67.99**	**68.01**	**68.02**	**68.52**	**68.63**	**69.25**	**69.59**	**69.93**
Wholesale, retail trade, restaurants and hotels	13.92	13.95	14.85	14.85	14.93	14.87	14.73	15.01	15.21	15.38	15.51	15.65
Transport, storage and communication	10.37	9.81	9.20	9.45	9.85	10.26	10.29	10.21	10.04	10.18	10.23	10.28
Other activities	41.19	42.87	43.16	43.27	43.20	42.88	42.99	43.30	43.39	43.70	43.85	44.01

Source: UNCTAD; NACI's linear forecast

A benchmarking of South Africa's value add in different economic sectors reveals a similarity of its economic structure compared with that of high-income countries, which are on average service-driven economies (see Table 5.2). Relative to other economies, upper middle-income countries have on average a large share of manufacturing value-added services as a percentage of GDP. In contrast, a relatively large share of the value-added products and services in South Africa's economy is in the mining and utility sectors.

Table 5.2: Benchmarking of value-added products and services by economic activity (2016)

	LOW-INCOME	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	SOUTH AFRICA
Agriculture, hunting, forestry and fishing	**28.41%**	**16.50%**	**7.62%**	**1.30%**	**2.43%**
Industry	**25.53%**	**30.25%**	**36.27%**	**24.34%**	**28.93%**
Mining and utilities	7.25%	6.9%	7.35%	4.40%	11.61%
Manufacturing	9.4%	16.15%	22.22%	14.73%	13.34%
Construction	8.88%	7.20%	6.72%	5.21%	3.98%
Services	**46.06%**	**53.25%**	**56.11%**	**74.36%**	**68.63%**
Wholesale, retail trade, restaurants and hotels	14.15%	15.17%	13.80%	14.65%	15.21%
Transport, storage and communication	8.15%	8.60%	6.30%	9.63%	10.04%
Other activities	23.75%	29.48%	36.02%	50.08%	43.39%

Source: UNCTAD

5.1.2 Merchandise exports by technological intensity

It has been argued that the sophistication of a country's production, and particularly its exports, is positively related to its economic growth. An explanation for this is that the production of more technology-intensive goods has a higher potential to generate economies of scale, productivity gains, knowledge spillovers and potential for backward and forward linkages. In this respect, South Africa appears to lag far behind the average of the upper middle-income countries in respect of high-technology exports (see Table 5.3).

Table 5.3: High-technology exports by income group

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	FORECAST		
											2018	2019	2020
Low-income countries	2	1	2	2	2	2	2	1	1	1	1	1	1
Lower middle-income countries	24	22	23	27	34	39	41	44	46	50	53	57	60
Upper middle-income countries	281	255	325	355	376	399	403	390	362	398	431	445	459
High-income countries	1 800	1 516	1 756	1 877	1 850	1 896	1 957	1 844	1 832	1 968	1 978	2 005	2 032
World average	424	363	427	457	460	476	486	461	448	482	495	503	512
South Africa	**50**	**38**	**55**	**62**	**63**	**58**	**65**	**60**	**54**	**50**	**60**	**61**	**62**

Source: UNCTAD; NACI's linear forecast

Since 2016, the country has lost its competitive edge in medium-technology exports in comparison to upper middle-income countries. This trend is likely to continue beyond 2020 unless there is a marked shift in the innovation landscape (see Table 5.4). The medium-technology category incorporates automotive products (passenger and goods motor vehicles, parts and accessories for these vehicles and motorcycles), engineering products (engines, machinery, plant, agricultural machinery, ships and instruments) and process products (fibres suitable for spinning, upstream chemicals, fertilizers, explosives, plastics, fabrics, steel, trailers, railway vehicles and cinematographic supplies).

The medium-technology area in which South Africa has a relative competitive strength is the automotive field, although, as one of the upper middle-income countries, it slipped from 4.8% in 2008 to 3.6% in 2017. Medium-technology exports from South Africa have been largely unchanged over the past decade, at around $450 per million inhabitants.

An area of particular weakness is the development of engineering products. During 2017, the country's proportion of exports in this field, by countries with a similar income, was just 1.0%, down from 1.7% in 2008.

Table 5.4: Medium-technology exports by income group

	USD PER MILLION INHABITANTS												
											FORECAST		
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low-income countries	4	4	4	4	4	4	4	3	3	4	3	3	3
Lower middle-income countries	44	34	44	53	54	56	56	48	49	55	57	59	60
Upper middle-income countries	328	249	327	393	414	427	445	428	407	447	482	499	516
High-income countries	3 124	2 297	2 736	3 203	3 109	3 138	3 188	2 878	2 858	3 088	3 105	3 131	3 157
World average	680	501	605	709	697	703	714	650	636	687	700	708	715
South Africa	**472**	**297**	**468**	**517**	**497**	**464**	**479**	**435**	**404**	**433**	**449**	**450**	**451**

Source: UNCTAD; NACI's 2030 linear forecast

Table 5.5 also shows South Africa's gradual loss of competitiveness in relation to low-technology products, an area in which the country is lagging far behind upper middle-income countries. By 2020, the country might even rank below lower-middle income countries. Low-technology products include items such as leather, textiles, fabrics, bags, clothing and footwear.

Table 5.5: Low-technology exports by income group

	USD PER MILLION INHABITANTS												
											FORECAST		
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low-income countries	6	5	5	6	6	6	6	6	5	5	5	5	5
Lower middle-income countries	64	58	67	81	81	85	89	86	88	95	100	104	107
Upper middle-income countries	270	216	266	320	344	366	392	363	332	346	395	409	422
High-income countries	1 117	856	961	1 107	1 051	1 068	1 096	988	971	1 044	1 035	1 036	1 038
World average	316	248	286	334	332	342	356	325	311	330	346	351	356
South Africa	**107**	**81**	**140**	**140**	**134**	**119**	**121**	**100**	**94**	**105**	**107**	**106**	**105**

Source: UNCTAD; NACI's linear forecast

5.2 INNOVATION FOR INCLUSIVENESS AND SOCIAL IMPACT

It is known that innovation is a key driver of economic growth, but the broader impact of innovation in society is less well understood. Innovation, especially in the context of emerging economies, may coexist with growing inequalities and social exclusion. Marginalised and vulnerable communities rarely participate in and benefit from the fruits of innovation-driven economic growth. It is therefore important to steer innovation efforts in a direction that results in more inclusive and equitable societies. The following section assesses various measures of social progress, allowing for the benchmarking of South Africa against peer countries and regions.

5.2.1 Human Development Index

Another non-market indicator of the country's progress over time is the Human Development Index (HDI). It measures health (life expectancy at birth), knowledge (expected and mean years of schooling) and a decent standard of living (gross national income (GNI) per capita). As illustrated in Table 5.6, South Africa ranks low on the HDI (113th) relative to the average of upper middle-income countries (90th). This low ranking mainly results from a very low ranking in the life expectancy at birth component (161st out of 189 countries).

Table 5.6: Equivalent rankings on HDI components

	OUT OF 189 COUNTRIES				
	HDI	LIFE EXPECTANCY AT BIRTH	EXPECTED YEARS OF SCHOOLING	MEAN YEARS OF SCHOOLING	GNI PER CAPITA
Low-income countries	171	166	172	170	62
Lower middle-income countries	131	134	135	128	98
Upper middle-income countries	90	92	81	86	62
High-income countries	30	37	31	43	14
World average	106	108	95	103	47
South Africa	**113**	**161**	**93**	**71**	**69**

Source: UNDP's 2018 Human Development Report

5.2.2 Social Progress Index

The Social Progress Index (SPI) is an alternative measure of a country's progress, in addition to the traditional indicator of GDP. It has the following three sub-indices:

- Basic human needs
- Foundations of wellbeing
- Opportunity

Table 5.7 illustrates the updated ranking of South Africa on the SPI for the past five years. As indicated, this index has been relatively stable in terms of South Africa's ranking over time in comparison with market-related indicators. In 2018, the country was ranked 77th out of 146 countries, which was the same rank it had in 2014. Similarly, on basic human needs, an area in which South Africa is not performing well, a ranking of 97th has been in place for five consecutive years.

The three areas that remain a huge challenge for South Africa are personal safety (135th in 2018), health and wellness (102nd) and nutrition and basic medical care (100th). Personal safety indicators include homicide rates, political killings, traffic deaths and perceived criminality.

Table 5.7: World ranking of South Africa on the SPI

COMPONENT	SUB-COMPONENT RANKING	OUT OF 146 COUNTRIES 2014	2015	2016	2017	2018
BASIC HUMAN NEEDS	Nutrition and basic medical care	104	102	100	99	100
	Water and sanitation	84	84	84	84	84
	Shelter	86	89	93	94	86
	Personal safety	136	135	133	133	135
	Sub-component ranking	**97**	**97**	**97**	**97**	**97**
FOUNDATIONS OF WELLBEING	Access to basic knowledge	81	82	81	80	80
	Access to information and communication	71	77	76	71	71
	Health and wellness	105	102	104	96	102
	Environmental quality	93	92	92	87	89
	Sub-component ranking	**86**	**88**	**87**	**86**	**86**
OPPORTUNITY	Personal rights	44	44	48	46	60
	Personal freedom and choice	40	40	39	40	41
	Inclusiveness	45	43	48	50	50
	Access to advanced education	55	56	39	49	53
	Sub-component ranking	**40**	**39**	**37**	**39**	**43**
SOCIAL PROGRESS RANKING		**77**	**79**	**76**	**75**	**77**

Source: Social Progress Imperative's Social Progress Index

South Africa's rankings on the SPI are benchmarked against countries' different economic groups in Table 5.8, based on SPI 2018. The equivalent rankings for upper middle-income countries confirm South Africa's weakness in satisfying basic human needs. In 2018, these countries ranked 75th on average on nutrition and basic medical care, whereas South Africa ranked only 100th. South Africa's ranking in this sub-component is a single notch below the average equivalent ranking of lower middle-income countries (99th). Personal safety, and health and wellness are two other areas in which South Africa ranks below the average of lower middle-income countries, namely 135th and 102nd respectively.

Although South Africa ranks low on foundations of wellbeing (86th), one area that matches the upper middle-income countries' average is access to information and communication (71st). The indicators included for this component are mobile telephone subscriptions, internet users, participation in online governance and access to independent media.

Table 5.8: Benchmarking of equivalent rankings on the SPI (2018)

COMPONENT	SUB-COMPONENT RANKING	OUT OF 146 COUNTRIES					
		LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	WORLD AVERAGE	SOUTH AFRICA
BASIC HUMAN NEEDS	Nutrition and basic medical care	133	99	75	32	91	100
	Water and sanitation	130	100	75	33	92	84
	Shelter	130	100	80	30	89	86
	Personal safety	108	104	88	25	76	135
	Sub-component ranking	**127**	**101**	**73**	**28**	**89**	**97**
FOUNDATIONS OF WELLBEING	Access to basic knowledge	128	102	74	31	89	80
	Access to information and communication	131	98	72	29	81	71
	Health and wellness	127	101	73	30	76	102
	Environmental quality	125	106	64	33	80	89
	Sub-component ranking	**129**	**101**	**71**	**28**	**85**	**86**
OPPORTUNITY	Personal rights	109	101	96	42	84	60
	Personal freedom and choice	132	99	71	21	77	41
	Inclusiveness	97	96	83	30	72	50
	Access to advanced education	128	89	68	26	68	53
	Sub-component ranking	**126**	**97**	**70**	**29**	**68**	**43**
SOCIAL PROGRESS RANKING		**132**	**100**	**66**	**27**	**81**	**77**

Source: Social Progress Imperative's Social Progress Index

Encouragingly, South Africa's performance in opportunity (43rd) surpasses by far the average of upper middle-income countries (70th). These countries, on average, have a poor record with regard to the protection of personal rights (political rights, freedom of expression, freedom of religion, access to justice and property rights for women) and inclusiveness (equality of political power, discrimination and violence against minorities, and acceptance of gays and lesbians). In the STI-related area, access to advanced education, the country is also performing well in comparison to upper middle-income countries.

6. KEY THEMES IN SOUTH AFRICAN STI POLICY

This chapter focuses on the following key STI policy themes:

- Regional innovation systems
- The Fourth Industrial Revolution
- The energy, nutrition security and water nexus

The regional and local innovation system concepts are becoming very important with a shift in focus from innovation spheres to spaces. The 4IR is a global trend that drives transformative change of socio-technical systems. The energy, nutrition security and water nexus is fundamental in achieving the sustainable development targets.

6.1 REGIONAL INNOVATION SYSTEMS

Considering the anticipated first-ever hosting of the Triple Helix Conference by South Africa since the first international conference was held in 1996, collaboration in real operational space between government, industry and academia should be a highlight on the 2019 calendar in South Africa. This section explores the strengths and weaknesses of various regional innovation systems at provincial level.

6.1.1 Provincial R&D performance

Due to the spillover nature of R&D, most system-level collaborations take place through knowledge generation, transfer and utilisation. As illustrated in Table 6.1, a large proportion of South African R&D expenditure takes place in Gauteng (46.0% in 2016/17), followed by Western Cape (23.3%). The three provinces with a low country share of R&D expenditure are Northern Cape (1.5%), Limpopo (2.0%) and Mpumalanga (2.0%). These are disturbing differences as they suggest that a high proportion of R&D expenditure takes place in urban areas as opposed to rural areas, which might exacerbate the relative underdevelopment of these areas.

The provincial patterns of R&D expenditure per sector reveal that dominant Triple Helix patterns are taking place. The provinces in which one expects the dominance of a university-push Triple Helix are Western Cape, Eastern Cape and Limpopo. In Western Cape, most of the R&D expenditure takes place at the University of Cape Town (UCT) (20%) and Stellenbosch University (18%). Stellenbosch University boosts numerous spin-off companies that are mainly housed at its Technopark. These traits of entrepreneurial support can also be found at UCT, CPUT and other universities and universities of technology.

In the Eastern Cape, Rhodes University has a large share of provincial R&D expenditure (14% in 2016/17), followed by Nelson Mandela University (13%) and University of Fort Hare (11%). These institutions of higher learning have not realised their full entrepreneurial potential. This is also the case with the University of Limpopo.

Table 6.1: Provincial R&D expenditure trends (2016/2017)

	EASTERN CAPE	FREE STATE	GAUTENG	KWAZULU-NATAL	LIMPOPO	MPUMALANGA	NORTHERN CAPE	NORTH WEST	WESTERN CAPE
Total R&D expenditure (billion R)	2 206	1 835	16 422	3 639	728	700	533	1 299	8 331
Provincial expenditure on R&D as a percentage of GERD	6.2	5.1	46.0	10.2	2.0	2.0	1.5	3.6	23.3
BERD (billion R)	690	1 060	7 876	1 553	172	285	527	50	2 567
Business's R&D as a percentage of provincial GERD	31.3	57.8	48.0	42.7	23.6	40.7	9.3	40.6	30.8

	EASTERN CAPE	FREE STATE	GAUTENG	KWAZULU-NATAL	LIMPOPO	MPUMALANGA	NORTHERN CAPE	NORTH WEST	WESTERN CAPE
Higher education's R&D as a percentage of provincial GERD	45.4	34.1	25.0	31.8	41.5	21.3	35.4	36.1	43.9
Science councils' R&D as a percentage of provincial GERD	12.4	3.3	19.6	13.1	15.8	18.4	41.9	8.3	18.3
Government's R&D as a percentage of provincial GERD	10.1	4.5	5.4	4.7	10.5	15.3	12.4	4.5	5.1
NPOs' R&D as a percentage of provincial GERD	0.8	0.4	2.0	7.6	8.8	4.3	0.9	10.5	1.8

Source: HSRC and DST's National Survey of Research and Experimental Development

The business-led innovation ecosystem is more prominent in the Free State, Gauteng, KwaZulu-Natal, Mpumalanga and North West. In all cases, the university R&D comes across as complementary to this dominant Triple Helix model. North West and KwaZulu-Natal also enjoy high levels of collaboration, as can be deduced from the high share of R&D expenditure by the not-for-profit organisation (NPO) sector. NPOs that perform R&D are typically formed by industry associations and intersectoral bodies.

Northern Cape is the only province in South Africa with characteristics of a government-pull Triple Helix model. The main drivers of innovation in this model are top-down science and technology missions. In the case of Northern Cape, the Square Kilometre Array (SKA) is a main mission that is coordinated by SKA South Africa. This innovation ecosystem model is dominant in China, where the government develops and promotes indigenous technologies through state-owned enterprises.

6.1.2 Government funding of STI at provincial level

The distribution of government support of STI initiatives in various provinces is illustrated in Table 6.2. This list is not comprehensive, as many government agencies do not disaggregate their data by province. Most of these innovation support instruments are based at the dti.

Table 6.2: Distribution of government support of STI initiatives at provincial level (most recent year)

	RECENT YEAR								
	EASTERN CAPE	FREE STATE	GAUTENG	KWAZULU-NATAL	LIMPOPO	MPUMALANGA	NORTHERN CAPE	NORTH WEST	WESTERN CAPE
Number of SEDA incubators	10	3	18	13	3	6	3	2	6
Cluster Development Programme disbursements (million R)	4.4	0	4.3	0	0	1.9	0	2.5	1.9
Number of students supported through THRIP	26	4	32	0	28	0	0	66	139
THRIP approvals (million R)	18.1	2.6	84.3	2.2	0	2.7	0	2.8	122.6
THRIP disbursements (million R)	2.2	0	5.8	2.2	0	1.9	0	0.3	7.6
Support Programme for Industrial Innovation (SPII) approvals (million R)	0	1.5	42.9	5	0	1.4	0	7.3	13.6

	RECENT YEAR								
	EASTERN CAPE	FREE STATE	GAUTENG	KWAZULU-NATAL	LIMPOPO	MPUMALANGA	NORTHERN CAPE	NORTH WEST	WESTERN CAPE
SPII disbursements (million R)	0	0.9	21.1	5	0	1.0	0	2.8	4.7
Manufacturing Investment Programme claims (million R)	1.4	0.3	28.5	15.7	0.5	17.9	20.9	10.2	2.5
Manufacturing Enhancement Support Programme disbursements (million R)	0.5	0	22.7	36.7	0	0	0	0	32.9

Source: Annual reports of various government departments

As expected, there is a smaller amount of innovation support taking place in Northern Cape as government is the main source of innovation in that province. One would have expected provinces such as Eastern Cape, Limpopo and Western Cape to have a large number of incubators and accelerators to support university-based entrepreneurial activities. Indeed, Eastern Cape has a large number of SEDA incubators (10), third only to Gauteng (18) and KwaZulu-Natal (13). Limpopo has only three and Western Cape has six.

It should be noted that some of the provinces might seem to be receiving less innovation support as their companies' head offices are in other provinces, such as Gauteng, Western Cape and KwaZulu-Natal.

6.1.3 Provincial innovation and entrepreneurship: Incubators

The best business incubation programmes are known to be well integrated into regional economic development plans and, as a direct success measure, they impact on their immediate communities[10].

Furthermore, it has been widely observed that other NSI institutions, such as universities, have become the central role players for the socioeconomic development of a region at regional level, as is evident from developments around leading global universities in Leuven, Oxford, Cambridge, Boston and Finland. At these institutions, the boundaries between the university and broader society have become increasingly blurred, especially in relation to the creation of specific technology-based industries where the university plays an important role in the establishment of an entrepreneurial ecosystem.

Belgium's Flanders region is a good example. KU Leuven (Leuven's research university) appears to demonstrate that the first step in the establishment of a knowledge region is for a critical mass of spin-out companies in a specific industry to emanate from universities in the region. This rapid start-up creation attracted entrepreneurs from outside the university who set up shop among the new university spin-outs. Significantly, infrastructure in the form of business incubators often follows soon after the increased start-up activity in a region[11].

It is currently estimated that there are 105 incubators in South Africa[12]. It is further estimated that 57% of these are supported by the public sector, primarily through SEDA, which supports 64 incubators[13]. Plans are reportedly underway to fund an additional 38 incubators in the next three to four years[14]. The provinces that are dominant in respect of number of incubators are Gauteng (which comprises 33% of the overall total), KwaZulu-Natal and Western Cape (see Table 6.3). This is to be expected as these provinces constitute the country's key economic hubs.

10 NBIA, 2014, *Case study: How one community fuelled entrepreneurship. A comprehensive guide to business incubation*, NBIA.
11 Ewalt, D, 2018, *Reuters Top 100: Europe's most innovative universities*, Reuters.
12 The dti, 2014.
13 Small Enterprise Development Agency (SEDA), 2018, *SEDA Annual Report* 2017/18.
14 Small Enterprise Development Agency (SEDA), 2018, 2018 Estimates of National Expenditure: Vote 31 Small Business Development Agency.

Table 6.3: Spread of South African incubators

PROVINCE	PERCENTAGE
Gauteng	33%
KwaZulu-Natal	15%
Western Cape	14%
Eastern Cape	11%
Mpumalanga	10%
Limpopo	5%
Northern Cape	5%
Free State	4%
North West	3%

There is a lack of information within the South African NSI about the overall design, characteristics and impact of incubators and accelerators. Another concern is the poor throughput of the supported companies, although there is currently no consolidated national database to explore this issue.

There is a wide range of business incubator types, models and incubation processes. Business incubators vary in many ways, including the following:

- The nature of their objectives
- The way they deliver their services
- Their organisational structure
- The types of clients they serve
- Their funding sources

Figure 6.1 provides an overview of four main incubator models in terms of the key components of these models.

CONFIGURATION	PRIVATE-PUBLIC MODEL	INSTITUTION-BACKED	VENTURE CAPITAL MODEL	CORPORATE SPONSORED
Profit orientation	Non-profit	Depends on institution	Profit motive very strong	Profit-oriented
Governance or sponsors	Corporate and institutional stakeholders	Corporate and institutional stakeholders	Individuals, angels and venture capital funds	Corporation
Main services provided	Rental space, shared services	Rental space, shared services, access to knowledge	Access to equity capital	Space, shared services and networks of experts
Sources of funding	Subsidies, fees and rent	Subsidies, fees and rent	Equity and fees	Equity, fees, sales
Incubation period	About three years	About three years	Shorter, can be months	No standard period

CONFIGURATION	PRIVATE-PUBLIC MODEL	INSTITUTION-BACKED	VENTURE CAPITAL MODEL	CORPORATE SPONSORED
Entry criteria	Promising idea or technology	Promising idea or technology	Promising technology, usually at a more developed stage	Promising technology or idea that will enhance incubator's position
Graduation criteria	Viability of business on its own	Viability of business on its own	Readiness for a liquidity event (initial public offering, merger and acquisition)	Incubator's discretion
Objectives	Local economic diversification, retaining businesses in the community, growing SMMEs	Technology transfer, commercialisation, clusters and developing entrepreneurship	Capitalise on investment and technological opportunities	Develop new and complementary technologies
Industry sector	Usually small services companies	Usually leading-edge technologies	New and emerging technologies	Technologies related to incubator's line of business
Management control	Management advice	Management advice	Management control	Direct of indirect management control
Relationship after graduation	None or casual	None or informal	None	Control or strong interest maintained

Figure 6.1: Principal characteristics of the main business incubation models

The distribution of incubators in South Africa according to their funding source is illustrated in Figure 6.2. With background provided above about the role of entrepreneurial universities for regional socioeconomic development, it is concerning to note that only 8% of the incubators are funded by universities or colleges.

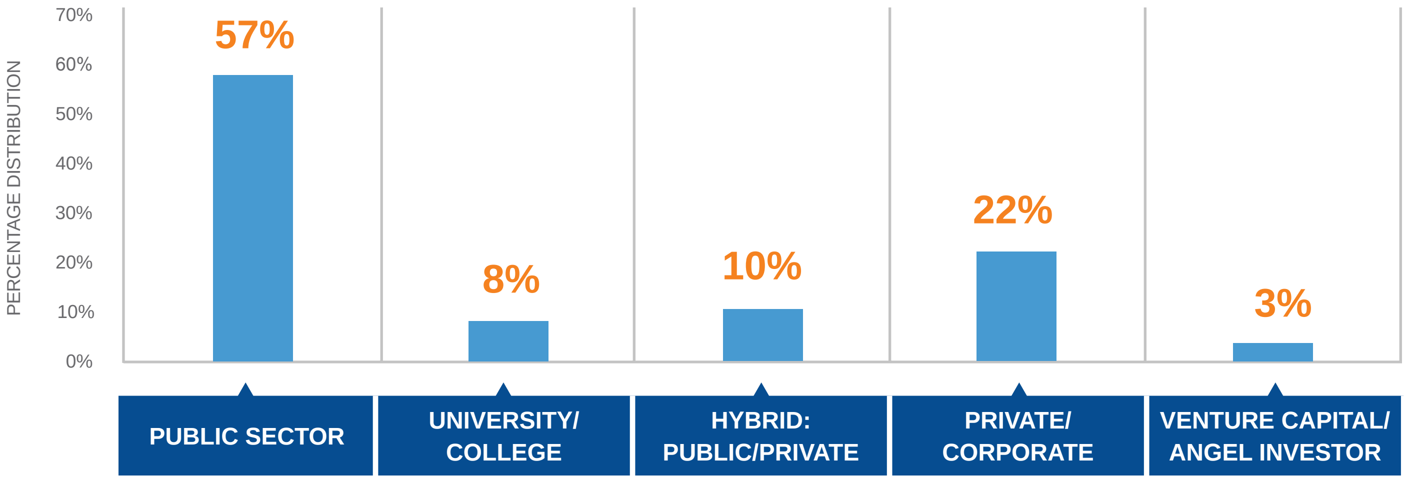


Figure 6.2: Incubator classification by funding source

6.2 THE FOURTH INDUSTRIAL REVOLUTION

The 4IR is a term coined by Klaus Schwab, founder and executive chairman of the World Economic Forum. It describes a world where individuals move between digital domains and offline realities with the use of connected technology to enable and manage their lives[15]. The 4IR is characterised by a fusion of technologies that is blurring the lines between the physical, digital and biological spheres. Technologies and trends such as IoT, robotics and AI are changing the way people live and work.

The aim of this section is to provide an indication of the state of the main relevant technologies and related topics in South Africa and the rest of the world according to the stage of development of various countries. Bibliometric analysis was used for this investigation. The following fields were analysed as part of the 4IR[16]: AI, robotics, IoT, autonomous vehicles, 3D printing, quantum computing and nanotechnology.

6.2.1 Research outputs in areas related to the 4IR

The Web of Science database was used to analyse the research outputs related to the 4IR. Different approaches, based mainly on key words, were utilised to identify the number of publications from South Africa on the various topics.

For nanotechnology, the results of a published article[17] on the topic were used. For research related to autonomous vehicles, searches were conducted on topics related to the following key words: “autonomous car”, “autonomous vehicle”, “autonomous automobile”, “driverless car”, “driverless vehicle”, “driverless automobile”, “self-driving car”, “self-driving vehicle”, “self-driving automobile”, “intelligent car” “intelligent vehicle” and “intelligent automobile”. All articles with South African authors published in relevant scientific journals, i.e. journals that include “autonomous vehicles” in their title, were included. The logic was that the editorial boards of those journals make sure that only relevant articles are published. With the latter approach, key words on a topic and in relevant journals were also utilised for the other research areas.

Appendix D summarises the number of South African publications on the different 4IR-related topics during the period 2007–2018, as well as the main organisations producing these publications, the Web of Science disciplines that contribute to the topic and the different countries that collaborate with South Africa on the production of these publications.

Table 6.4 illustrates the number of South African publications in different fields during the period 2016–2017, the number of world publications per field during the period 2016–2017, as well as the South African share within the number of world publications. South Africa has the highest contribution in terms of its world share in respect of the topics AI and IoT.

Table 6.4: South African share in world publications on 4IR

TECHNOLOGY	SOUTH AFRICAN PUBLICATIONS	WORLD PUBLICATIONS	SOUTH AFRICA’S SHARE
Nanotechnology	2 034	375 247	0.54%
Quantum computing	12	2 497	0.48%
Artificial intelligence	78	7 698	1.01%
Robotics	111	42 466	0.26%
3D printing	26	7 632	0.33%
Autonomous vehicles	69	12 174	0.56%
Internet of Things	92	13 402	0.68%

For comparative purposes, estimates were made for the number of publications in each technology produced by countries at different levels of development, as classified by the World Bank (see Table 6.5).

15 Miller, D. 2015, Natural language: The user interface for the Fourth Industrial Revolution, *Opus Research Report*.
16 Schwab, K. 2016, *The Fourth Industrial Revolution*, World Economic Forum, Davos
17 Maghreb, M., Abbasi, A., Amiri, S., Monsefi, R., Harati, A., 2011, A collective and abridged lexical query for delineation of nanotechnology publications, *Scientometrics*, 86:15–25.

Table 6.5: Number of 4IR publications from different countries (2016–2017)

	HIGH-INCOME COUNTRIES	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES
Autonomous vehicles	7 158	37	1 058	1 339
Artificial intelligence	3 874	10	1 205	1 728
3D printing	4 509	110	342	621
Robotics	25 805	1 343	3 969	5 450
Nanotechnology	241 834	496	46 684	49 728
Quantum computing	1 459	2	214	189
Internet of Things	7 967	13	2 213	1 506

The sum of the publications by different countries does not equal the total number of world publications because of collaborative publications.

As expected, the majority of publications in all technologies is produced by high-income countries. Upper middle-income countries follow, while low-income countries produce a minimal amount of relevant research.

Table 6.6 illustrates the share of each income group related to the prevalence of publications by 4IR topic. Not surprisingly, the range of share of publications produced by high-income countries ranges from a relatively high 50% of publications in AI to even greater shares above 60% in nanotechnology, robotics, autonomous vehicles and quantum computing.

Table 6.6: Share of 4IR publications produced by different countries (2016–2017)

	HIGH-INCOME COUNTRIES	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES
Autonomous vehicles	60.3%	0.3%	8.9%	11.3%
Artificial intelligence	50.3%	0.1%	15.7%	22.4%
3D printing	57.2%	1.4%	4.3%	7.9%
Robotics	60.8%	3.2%	9.3%	12.8%
Nanotechnology	64.4%	0.1%	12.4%	13.3%
Quantum computing	60.3%	0.1%	8.9%	7.8%
Internet of Things	59.4%	0.1%	16.5%	11.2%

Table 6.7 illustrates the number of publications per million of the population on 4IR topics over the two-year period between 2016 and 2017. While it is expected that the variability of the populations will affect the relative comparisons, the high-income countries again produced more publications per million of the population.

Table 6.7: 4IR publications per million of the population (2016–2017)

	HIGH-INCOME COUNTRIES	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES
Autonomous vehicles	5.731	0.051	0.356	0.520
Artificial intelligence	3.102	0.014	0.405	0.671
3D printing	3.610	0.150	0.115	0.241
Robotics	20.659	1.834	1.335	2.116
Nanotechnology	193.612	0.677	15.705	19.303
Quantum computing	1.168	0.003	0.072	0.073
Internet of Things	6.378	0.018	0.744	0.585

6.2.2 Readiness of South Africa for the 4IR

The 4IR is still in its early stages and it is predicted to have radical implications for economic and social development, among other aspects, all over the world. In South Africa, without any programmatic activity (with the exception of nanotechnology), the science community is producing a certain amount of relevant research, albeit limited.

The Minister of Communications established a Presidential Advisory Commission for the 4IR. The invitation for the nomination of relevant candidates (Notice 764 of 2018, Department of Telecommunications and Postal Services) states: "The Commission will coordinate the development of South Africa's national response through a comprehensive action plan to deal with the Fourth Industrial Revolution. As part of this effort, the Commission will identify and recommend policies, strategies and plans that are needed to position South Africa as one of the leading countries in the evolution and development of the Fourth Industrial Revolution".

6.3 ENERGY, NUTRITION AND WATER NEXUS

As shown by Maslow's hierarchy of needs, the primary objective of human civilisation is survival through the fulfilment of basic needs such as water, energy and nutrition. It is therefore through these three focus areas that STI can contribute to social innovation and the attainment of quality of life for all South Africans.

6.3.1 Conceptual framework

The framework used in this report to analyse the landscape developments within the energy, nutrition and water nexus is the one proposed by the Water Research Commission (see Appendix A).

This framework incorporates the vital drivers of change and challenges that South Africa must deal with, strongly influencing the nexus. What this framework also incorporates is the need for proper policies, strategies and the consideration of alternative clean, renewable options, a state of human wellbeing and environmental sustainability. Lastly, this nexus framework describes interactions between the three spheres of water, energy and nutrition security.

6.3.2 Assessing the nexus of scientific and technological developments

The analytical approach that is adopted for analysing the nexus in this report focuses on the scientific and technological developments for each sphere of the nexus, as well as for crosscutting issues.

Water and sanitation landscape

The Blue Drop (water supply system quality) and Green Drop (waste treatment system quality) status of South African water and sanitation systems are useful indicators that are included in the 2015 Water RDI Roadmap to monitor operational efficiency. The full assessment criteria for Blue Drop certification include the following:

- Water safety planning
- Process management and control
- Drinking water quality verification
- Management accountability and local regulation
- Asset management

The research initiatives that are earmarked for water and waste treatment works include the ability to monitor and evaluate the public sector system and its performance, including through technology insertion, service responsiveness and upgrading of capacity. The Water RDI Roadmap has a target of more than 90% on both Blue Drop and Green Drop certification standards.

Table 6.8 illustrates that, nationally, out of the 1 036 water systems assessed in 2014, only 44 achieved Blue Drop status. The national Blue Drop average score declined by 8% from 2012 to 2014. According to the Department of Water and Sanitation (DWS), the factors influencing this decline might have included the limited application of water safety planning and the introduction of the No Drop criteria, which looks at managing water losses within supply systems.

Table 6.8: National performance on the quality of water supply

	2009	2010	2011	2012	2014
National Blue Drop score (%)	51.4	67.2	72.9	87.6	79.6
Number of systems achieving Blue Drop Status	25	38	66	98	44
Number of systems assessed	402	787	914	931	1 036

Source: Briefing Notes on the 2014 Blue Drop Report

At the provincial level (see Table 6.9), in 2014, Gauteng was the only province that exceeded the Blue Drop performance of 90%, up from 74% in 2009. Western Cape and KwaZulu-Natal also performed relatively well.

Table 6.9: Blue Drop performance at provincial level

	2009	2010	2011	2012	2014
Eastern Cape	41%	55%	64%	82%	72%
Free State	54%	79%	77%	82%	75%
Gauteng	74%	86%	95%	98%	92%
KwaZulu-Natal	73%	66%	80%	92%	86%
Limpopo	51%	65%	57%	79%	62%
Mpumalanga	40%	66%	62%	61%	69%
North West	28%	47%	62%	79%	63%
Northern Cape	40%	49%	64%	68%	68%
Western Cape	60%	92%	94%	94%	89%

Source: Briefing Notes on the 2014 Blue Drop Report

Nutrition security landscape

The plant breeders' right (PBR) is an ideal indicator for technological innovations that relate to nutrition security. This is true as addressing multiple challenges that face global agriculture requires integrated innovation in areas such as seeds, biotechnology, crop protection, grain storage and transport[18]. Figure 6.3 illustrates an annual trend of PBRs that is in force.

18 Nhemachera, C.R., Liebenberg, F.G., Kirsten, J. 2016, The evolving landscape of plant breeders' rights regarding wheat varieties in South Africa, *South African Journal of Science*, 112(3/4):1–8.

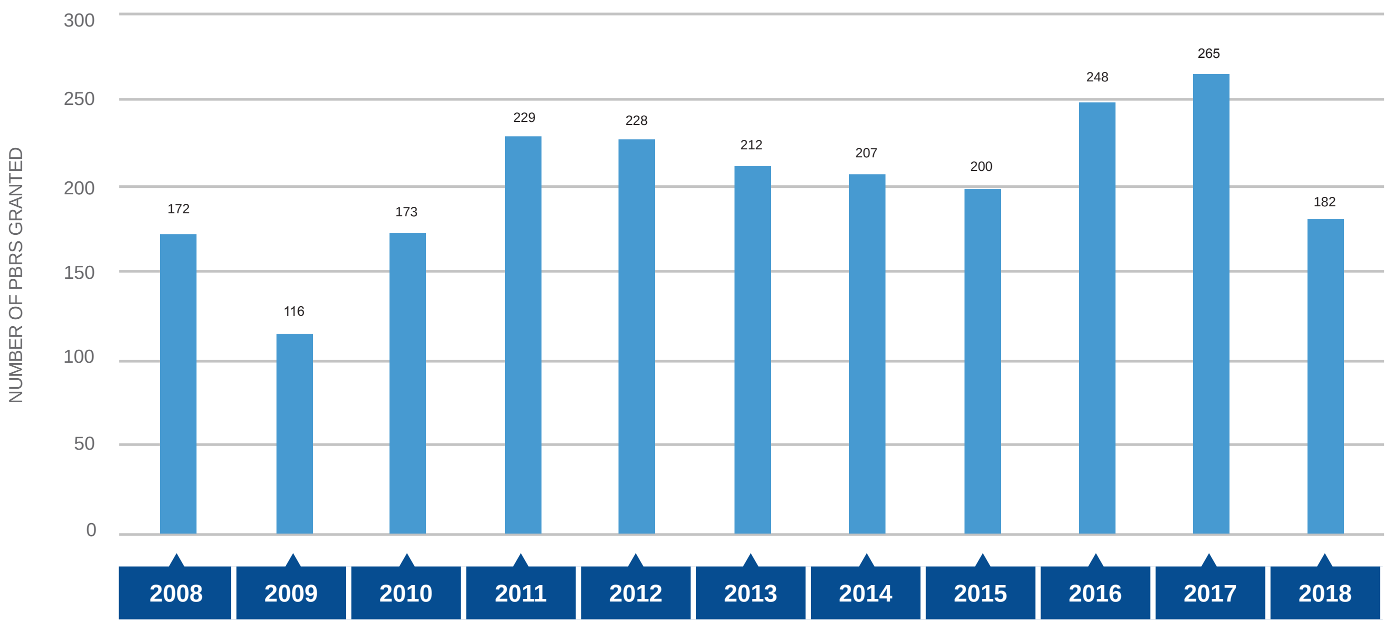


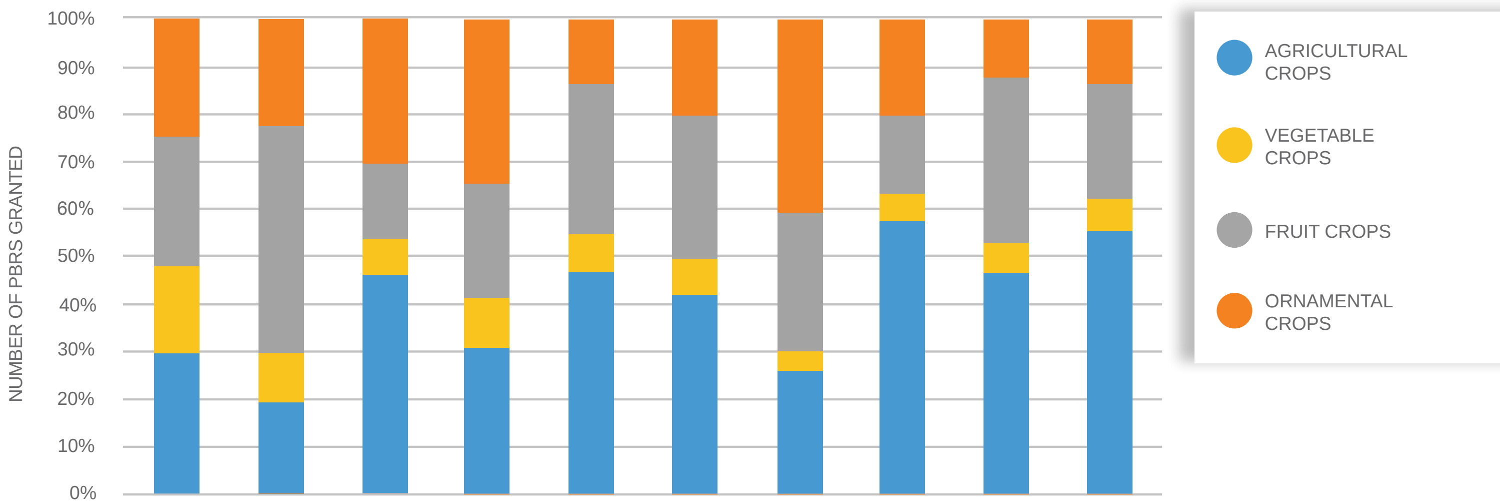
Figure 6.3: Trend in the annual number of PBRs granted

Source: Department of Agriculture, Forestry and Fisheries

Following a long period of PBRs granted between 2011 and 2015, more PBRs were granted in 2016 (248) and 2017 (265). Only 182 PBRs were granted in 2018. It should be noted that a PBR is valid for a period of 20 or 25 years, depending on the kind of plant.

Although PBRs granted by type are highly variable per annum, most PBRs are granted for agricultural crops (see Figure 6.4). In 2017, approximately 55.8% of PBRs were granted in this category, followed by fruit crops (24.2%), ornamental crops (13.6%) and vegetable crops (6.4%).

The main driver behind the large proportion of PBRs granted for agricultural crops is genetically modified organisms (GMOs).



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agricultural crops	52	23	80	71	107	89	54	115	116	148
Vegetable crops	31	12	13	25	18	16	7	12	16	17
Fruit crops	47	55	29	54	72	64	62	33	86	64
Ornamental crops	42	26	51	79	31	43	84	40	30	36

Figure 6.4: Trend in the annual number of PBRs granted by type

Source: Department of Agriculture, Forestry and Fisheries

As illustrated in Table 6.10, almost all GMO-based PBR grants are for agricultural crops. GMOs are found mainly in soya beans, white maize and yellow maize. According to agricultural experts, approximately 99% of soya and 84% of maize in South Africa are GMO based[19]. The benefits of GMO crops may include insect or pest resistance, disease resistance, withstanding environmental stresses such as drought, herbicide tolerance and improving the nutritional value of the crop.

Table 6.10: Number of GMO PBRs granted by type

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agricultural crops	25	1	36	29	49	27	29	64	55	73
Soya beans	3	1	3	10	0	9	7	22	16	18
Cotton	0	0	4	0	0	0	2	2	0	1
White maize	13	0	4	10	25	4	11	17	21	31
Yellow maize	9	0	25	9	24	14	9	23	18	23
Vegetable crops	0	0	0	0	0	0	0	0	0	0
Fruit crops	0	0	0	0	0	0	0	0	0	0
Ornamental crops	0	0	0	0	0	0	0	0	0	0
Total	**25**	**1**	**36**	**29**	**49**	**27**	**29**	**64**	**55**	**73**

Source: Department of Agriculture, Forestry and Fisheries

Technological innovation adds significant value to field crops as can be seen in Figure 6.5 and Figure 6.6. Both soya beans and maize experienced a significant increase in production and gross value in comparison to the plantation area.

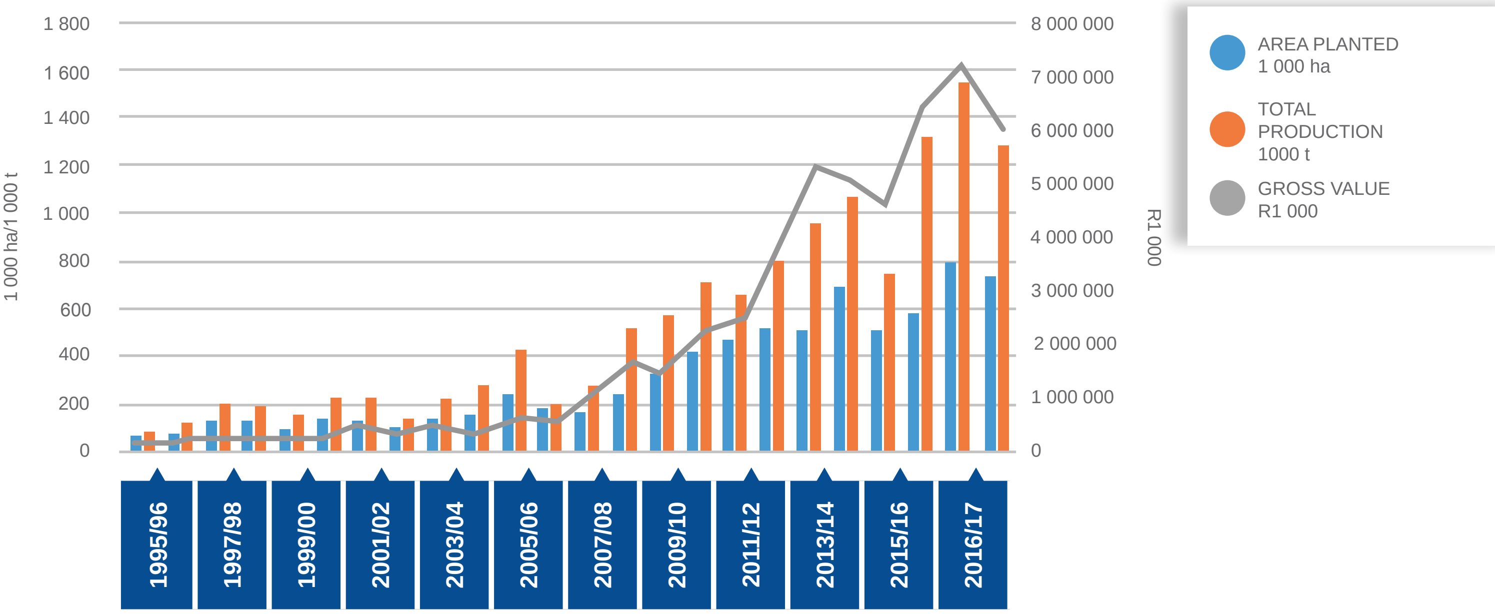


Figure 6.5: Annual productivity/value of soya beans and area planted

Source: Department of Agriculture, Forestry and Fisheries' Abstract of Agricultural Statistics 2019

This increase in productivity and value added is more visible in the case of maize (see Figure 6.6). Although the area planted decreased from 3.3 million hectares in 2000/01 to 2.6 million hectares in 2018/19, the total production for maize increased from 7.8 million tons in 2000/01 to a peak of 14.9 million tons in 2016/17, followed by a decline to 8.2 million tons in 2018/19.

19 https://www.health-e.org.za/

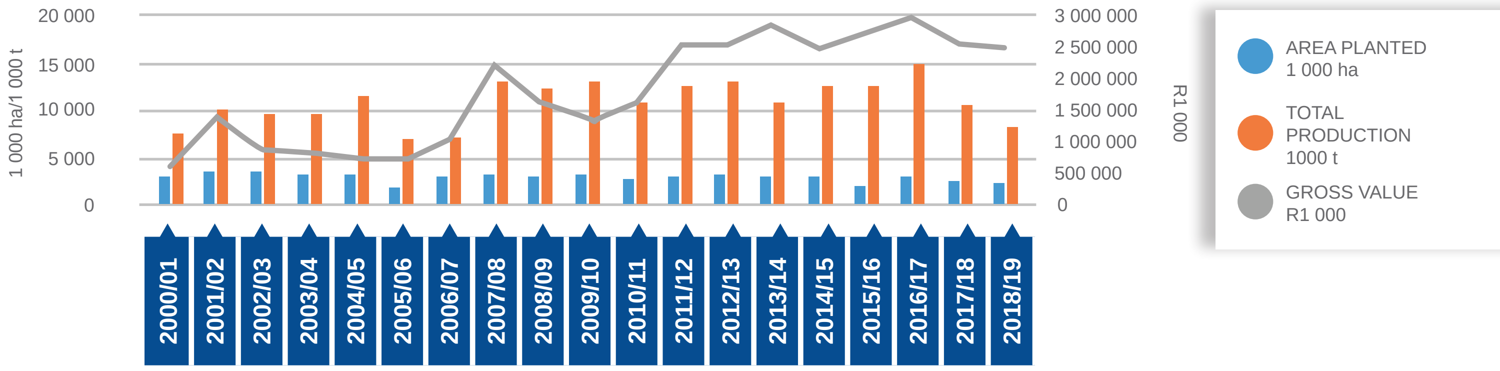


Figure 6.6: Annual productivity/value of maize and area planted

Source: Department of Agriculture, Forestry and Fisheries' Abstract of Agricultural Statistics 2019

Another example of the impact of technological innovation on nutrition security is with regard to dry beans. Varieties that are resistant to disease and drought can be grown in South African environments. These varieties have improved canning and culinary attributes. Productivity of these varieties are important for food and nutrition in the household[20]. Dry beans are an important source of protein, carbohydrates and soluble fibre for a large sector of the South African population

Figure 6.7 shows the significant contribution of the Agricultural Research Council (ARC) to the production of dry bean varieties in South Africa. This contribution, as part of the ARC's Dry Bean Breeding Programme, has increased over the years, with 2014 being the highest. The varieties for production on hectares plays an important role to the producers and in food security.

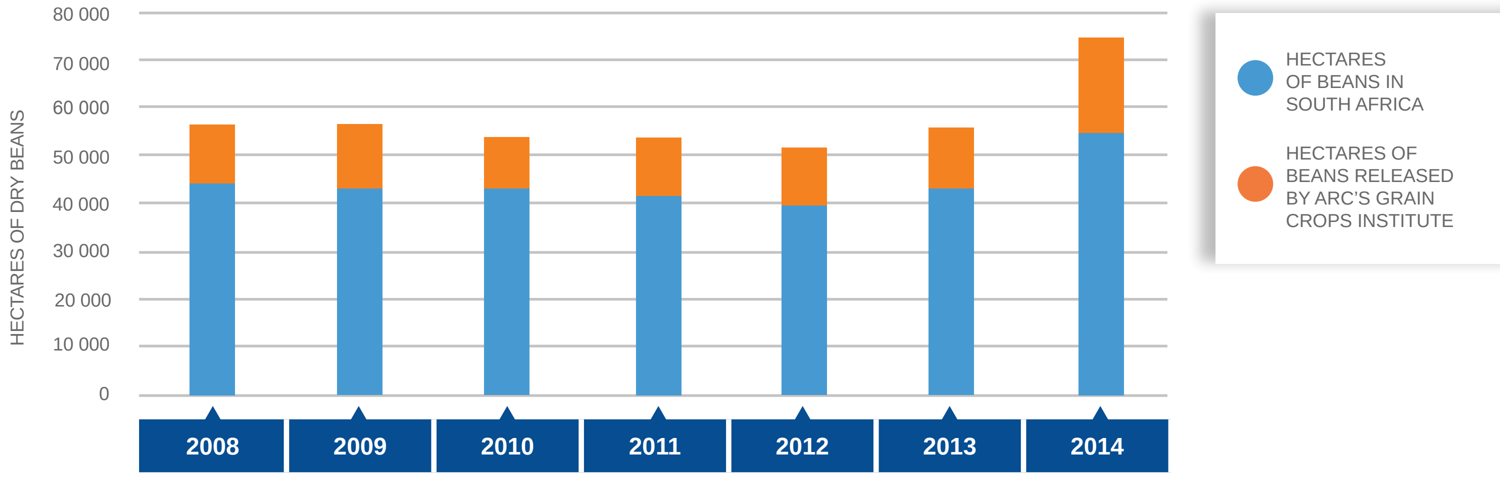


Figure 6.7: Hectares of dry beans in South Africa, released by ARC

Source: Agricultural Research Council

Energy landscape

The country remains heavily reliant on coal for electricity generation (see Table 6.11), although coal, as a share of the total, is on the decline, albeit at a very gradual pace. Electricity generation in the form of hydroelectricity is also on the decline. This is possibly due to recent incidents of drought. This is a good example of how constraints within the water system affect the energy generation system. There is less reliance on natural gas, although, in the long term, this might change due to the recent discovery of gas as an energy source.

20 Dlamini, TS., 2015. *The genetic and economic impacts of the National Dry Bean Breeding Programme in South Africa*, 1980–2014.

Table 6.11: Proportion of electricity production from alternative sources

	PERCENTAGE OF TOTAL ELECTRICITY PRODUCTION										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coal	94.27	94.10	94.26	93.80	94.63	93.74	93.10	92.71	92.93	92.74	92.54
Hydro-electricity	0.47	0.57	0.82	0.79	0.47	0.46	0.39	0.32	0.36	0.32	0.28
Natural gas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nuclear energy	5.09	5.19	4.71	5.20	4.69	5.57	5.53	5.43	5.51	5.58	5.66
Oil	0.06	0.02	0.08	0.08	0.08	0.08	0.08	0.07	0.09	0.09	0.10
Renewables*	0.06	0.02	0.08	0.08	0.08	0.08	0.08	0.07	0.09	0.09	0.10

* Excluding hydro-electricity

Source: The World Bank; NACI's liner forecast

Figure 6.8 illustrates the distribution of renewable energy sources (including hydro-electricity) in 2016. Although hydro-electricity's contribution to the grid is on the decline, its share of renewable energy sources remains the largest (37% in 2006), followed by wind (34%) solar photovoltaic (PV) panels (24%) and solar thermal electricity (5%).

South Africa lags behind many economies with regard to renewables as sources of electricity production (see Table 6.12). High-income countries were increasingly adopting renewable energy sources (9.51%) in 2015, followed by upper middle-income countries (4.35%) and lower middle-income countries (4.29%). The country even lags behind the average of low-income countries in adopting renewable energy technologies for electricity production. This indicates the presence of carbon lock-in, caused by the abundance of relatively cheap coal deposits in the country.

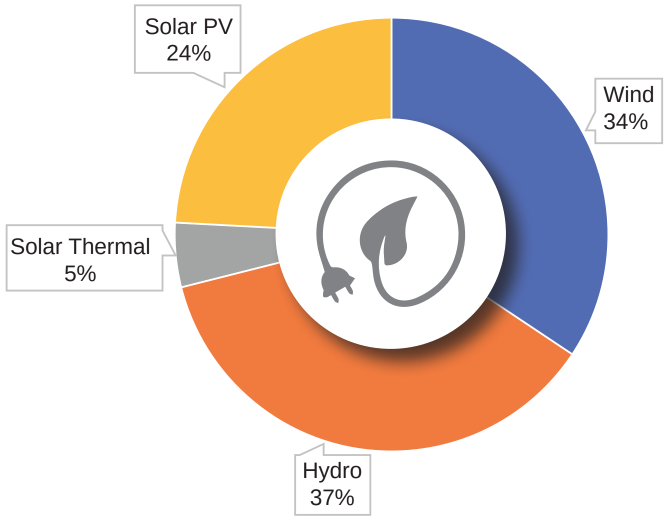


Figure 6.8: Share of sources in renewable electricity generation (2016)

Source: International Energy Agency

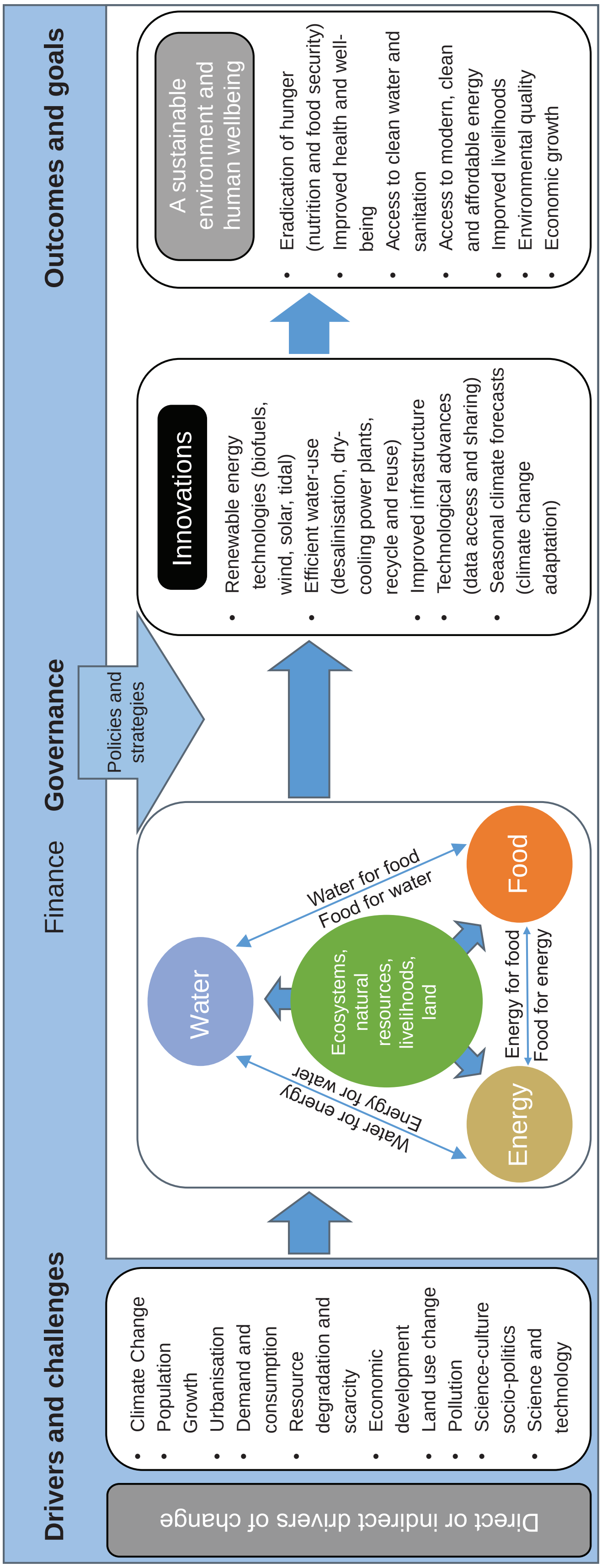
Table 6.12: Proportion of electricity production from renewable sources

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Low-income countries	0.08%	0.08%	0.11%	0.15%	0.25%	0.37%	0.44%	0.61%	0.60%	0.68%	0.76%
Lower middle-income countries	2.64%	2.96%	2.98%	3.20%	3.53%	3.75%	4.07%	4.29%	4.49%	4.72%	4.95%
Upper middle-income countries	0.98%	1.30%	1.67%	1.97%	2.39%	3.11%	3.62%	4.35%	4.56%	5.04%	5.51%
High-income countries	3.77%	4.41%	5.01%	5.92%	6.80%	7.73%	8.55%	9.51%	10.21%	11.04%	11.87%
World average	2.68%	3.13%	3.55%	4.10%	4.70%	5.41%	6.01%	6.77%	7.18%	7.77%	8.35%
South Africa	**0.06%**	**0.02%**	**0.08%**	**0.08%**	**0.08%**	**0.08%**	**0.08%**	**0.07%**	**0.09%**	**0.09%**	**0.10%**

Source: The World Bank; NACI's linear forecast

APPENDIX A:

FRAMEWORK FOR THE WATER, ENERGY AND NUTRITION SECURITY NEXUS



Source: Water Research Commission's Assessing the state of the water, energy, food nexus in South Africa

APPENDIX B:

SELECTED DATA FROM THE 2018 ASSESSMENT OF TT100 ORGANISATIONS

Management of technology

Table B1: Technology management strategies by TT100 organisations (2018)

Organisations with a technology management strategy	78.38%
Organisations with S-curves as a technology decision-making tool	45.95%
Organisations with Stage-Gate processes as a technology decision-making tool	45.95%
Organisations using technology roadmaps as a technology decision-making tool	93.10%
Organisations sourcing technology from abroad	32.43%

Source: Da Vinci Institute

Management of innovation

Table B2: Innovation management strategies by TT100 Organisations (2018)

Organisations with an innovation management strategy	81.08%
Organisations with product innovation	100.00%
Organisations with process innovation	82.76%
Organisations with service innovation	93.10%
Organisations with people innovation	65.52%
Organisations impacted on negatively by government policy	31.25%

Source: Da Vinci Institute

Management of people

Table B3: People management strategies by TT100 organisations (2018)

Organisations with a people management strategy	45.94%
Organisations offering specialised training to retain core skilled employees	47.06%
Organisations offering share ownership options to retain core skilled employees	11.76%
Organisations creating a culture of meaningful work to retain core skilled employees	52.94%
Organisations in which employees have a degree of control over their compensation package	47.06%
Organisations in which employees have a degree of control over their working hours	47.06%
Organisations in which employees have a degree of control over their leave timing (annual leave not enforced by shutdowns or maintenance	26.32%

Source: Da Vinci Institute

Management of systems

Table B4: Systems management strategies by TT100 Organisations (2018)

Organisations that integrate innovation, people and technology activities and practices	51.35%
Organisations collaborating with key competitors and government on common issues facing their industry	68.42%
Organisations meeting with government agencies in an attempt to improve the competitive positioning of their organisation and/or industry	68.42%
Organisations impacted on negatively by government policy	31.25%
Organisations with an IP management strategy	52.63%
Organisations using patent registration to protect their IP	42.11%
Organisations with a dedicated R&D department	10.81%
Organisations with an R&D facility that is located on the same premises as it conducts its normal business operations	32.43%

Source: Da Vinci Institute

APPENDIX C:

PATENT STATISTICS

Table C1: Proportion of residents' patent publications (2008–2017)

TECHNOLOGY	LOW-INCOME COUNTRIES	LOWER MIDDLE-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	HIGH-INCOME COUNTRIES	SOUTH AFRICA
Unknown	2.4	19.3	42.8	65.3	11.4
Electrical machinery, apparatus, energy	0.8	40.7	71.6	62.4	19.3
Audio-visual technology	0.0	20.3	57.2	58.6	20.1
Telecommunications	3.1	29.7	68.8	59.5	13.2
Digital communication	0.6	9.5	73.2	50.9	4.7
Basic communication processes	0.0	53.0	60.0	54.6	15.9
Computer technology	2.4	38.0	73.1	59.1	14.8
IT methods for management	5.1	37.5	80.6	75.1	26.8
Semiconductors	0.0	34.3	51.2	56.3	8.3
Optics	0.0	28.9	52.6	61.8	7.4
Measurement	1.1	62.1	83.3	62.6	11.3
Analysis of biological materials	0.0	48.2	73.5	50.2	9.4
Control	3.3	49.4	83.4	67.9	24.2
Medical technology	4.4	42.0	60.4	54.2	7.1
Organic fine chemistry	0.7	13.0	59.7	41.8	1.1
Biotechnology	0.5	17.4	67.7	43.8	2.9
Pharmaceuticals	1.3	15.0	68.2	36.2	1.6
Macromolecular chemistry, polymers	3.0	19.9	72.6	51.8	3.1
Food chemistry	1.1	46.6	89.8	65.2	4.9
Basic materials chemistry	0.8	19.8	77.8	50.7	4.9
Materials and metallurgy	0.5	42.3	84.7	60.4	7.5
Surface technology, coating	0.0	37.2	74.5	57.2	5.9
Micro-structural and nanotechnology	0.0	68.4	82.2	59.8	6.7
Chemical engineering	0.3	41.3	80.4	59.5	10.1
Environmental technology	0.0	43.2	84.6	67.7	15.6
Handling	0.8	20.3	75.4	68.4	18.7
Machine tools	0.0	45.2	85.5	65.5	13.1
Engines, pumps, turbines	0.5	47.0	60.8	62.6	10.9
Textile and paper machines	2.1	23.9	73.5	65.1	6.4
Other special machines	1.1	51.9	83.2	67.6	16.3
Thermal processes and apparatus	0.9	41.9	81.9	72.3	20.0
Mechanical elements	2.8	37.7	70.2	65.7	25.2
Transport	0.0	42.3	62.9	69.4	24.4
Furniture, games	2.4	38.4	77.7	78.8	22.1
Other consumer goods	1.4	21.5	75.1	70.2	25.4
Civil engineering	0.0	41.2	83.1	74.3	34.0
All technologies	**0.0**	**28.8**	**83.9**	**61.7**	**12.4**

Source: WIPO's IP Statistics Data Centre

APPENDIX D:

SCIENTIFIC PUBLICATIONS RELATED TO THE 4IR

Table D1: Autonomous vehicles

ANNUAL NUMBER OF PUBLICATIONS	
2007	4
2008	9
2009	4
2010	6
2011	7
2012	11
2013	22
2014	21
2015	26
2016	41
2017	28
2018	14

MAIN PRODUCERS	
University of KwaZulu-Natal	32
University of Cape Town	29
University of Pretoria	23
Stellenbosch University	21
University of the Witwatersrand	21
CSIR	19
University of Johannesburg	18
North West University	15

WEB OF SCIENCE DISCIPLINES	
Engineering electrical electronics	54
Robotics	27
Automation control systems	26
Computer science artificial intelligence	19
Energy fuels	17
Transportation science technology	15
Computer science theory methods	11
Engineering chemicals	11
Engineering mechanical	11

COLLABORATING COUNTRIES	
South Africa	214
France	22
Iran	13
USA	12
England	11
Australia	8

Table D2: 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	52
2018	21

MAIN PRODUCERS	
University of Pretoria	42
CSIR	29
University of the Western Cape	15
University of Cape Town	14
University of South Africa	14
Central University of Technology	10
University of Johannesburg	10

WEB OF SCIENCE DISCIPLINES	
Engineering electrical electronics	59
Computer science information systems	48
Computer science theory methods	36
Telecommunications	34
Computer science information applications	20
Computer science hardware analysis	18

COLLABORATING COUNTRIES	
South Africa	155
China	23
USA	12
Canada	7
France	7
Germany	5

Table D3: 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	16
2017	10
2018	12

MAIN PRODUCERS	
Stellenbosch University	21
University of Pretoria	10
University of the Witwatersrand	6
Central University of Technology	5
University of Cape Town	5
University of Johannesburg	5
University of KwaZulu-Natal	4
North West University	3

WEB OF SCIENCE DISCIPLINES	
Engineering manufacturing	13
Material sciences multidisciplinary	10
Engineering industrial	9
Engineering mechanical	8
Engineering electrical electronics	7
Engineering biomedical	5
Robotics	5
Automation control systems	4
Engineering chemicals	3

COLLABORATING COUNTRIES	
South Africa	58
USA	5
England	3
France	3
Germany	3
Australia	2
Austria	2
China	2
Singapore	2

Table D4: Quantum computing

ANNUAL NUMBER OF PUBLICATIONS	
2007	1
2008	4
2009	4
2010	1
2011	3
2012	5
2013	1
2014	11
2015	4
2016	7
2017	5
2018	6

MAIN PRODUCERS	
University of KwaZulu-Natal	35
University of Johannesburg	14
University of the Witwatersrand	9
CSIR	4

WEB OF SCIENCE DISCIPLINES	
Physics multidisciplinary	23
Optics	13
Physics mathematical	11
Physics atomic molecular chemistry	9
Physics application	8

COLLABORATING COUNTRIES	
South Africa	65
Germany	6
USA	6
England	5
Canada	4
France	4
Mexico	4

Table D5: Nanotechnology

ANNUAL NUMBER OF PUBLICATIONS	
2007	135
2008	185
2009	229
2010	306
2011	361
2012	469
2013	579
2014	656
2015	767
2016	984
2017	1 050
2018	1 112

MAIN PRODUCERS	
University of Johannesburg	1 138
University of the Witwatersrand	985
CSIR	878
University of KwaZulu-Natal	848
University of South Africa	646
University of the Free State	607
University of Pretoria	562

WEB OF SCIENCE DISCIPLINES	
Material science multidisciplinary	1 731
Chemistry physical	1 165
Physics applied	955
Chemistry multidisciplinary	909
Nanoscience nanotechnology	778
Physics condensed matter	723
Polymer science	583

COLLABORATING COUNTRIES	
South Africa	7 457
India	909
USA	465
England	303
Germany	301
Nigeria	277

Table D6: Robotics

ANNUAL NUMBER OF PUBLICATIONS	
2007	4
2008	10
2009	10
2010	15
2011	13
2012	39
2013	44
2014	37
2015	44
2016	53
2017	58
2018	32

MAIN PRODUCERS	
University of KwaZulu-Natal	70
CSIR	52
University of Cape Town	56
University of Pretoria	55
University of Johannesburg	43
Tshwane University of Technology	30
University of the Witwatersrand	27
Stellenbosch University	24

WEB OF SCIENCE DISCIPLINES	
Engineering electrical electronics	125
Computer science	117
Robotics	112
Automation control systems	63
Computer science theory methods	44
Engineering mechanical	28
Astronomy astrophysics	25
Computer science interdisciplinary applications	20
Computer science informatics	19

COLLABORATING COUNTRIES	
South Africa	426
USA	34
Germany	31
England	27
France	23
China	20
Spain	15
Argentina	10

Table D7: Artificial intelligence

ANNUAL NUMBER OF PUBLICATIONS	
2007	8
2008	5
2009	8
2010	6
2011	3
2012	13
2013	16
2014	4
2015	18
2016	31
2017	47
2018	24

MAIN PRODUCERS	
University of Johannesburg	50
University of KwaZulu-Natal	38
University of Pretoria	29
University of Cape Town	24
Stellenbosch University	19
University of the Witwatersrand	18
Tshwane University of Technology	16

WEB OF SCIENCE DISCIPLINES	
Computer science artificial intelligence	57
Engineering electrical electronics	39
Computer science information systems	33
Computer science theory methods	29
Energy fuels	20
Economics	18
Engineering chemical	17
Automation control systems	11

COLLABORATING COUNTRIES	
South Africa	228
USA	15
France	11
Iran	11
Austria	9
England	7

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