SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS 2017

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SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION INDICATORS

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ACRONYMS

Acronym	Definition
AIDS	Acquired Immune Deficiency Syndrome
APAP	Agricultural Policy Action Plan
APEC	Asia-Pacific Economic Cooperation
ARC	Agricultural Research Council
BERD	Business Expenditure on Research and Development
BRICS	Brazil, Russia, India, China and South Africa
CBTBR	Centre of Excellence for Biomedical Tuberculosis Research
CESM	Classification of Education Subject Matter
CHP	Combined Heat and Power
CIPC	Companies and Intellectual Property Commission
CPSI	Centre for Public Service Innovation
CSF	Commercialisation Support Fund
CSIR	Council for Scientific and Industrial Research
CUT	Central University of Technology
DAFF	Department of Agriculture, Forestry and Fisheries
DIRISA	Data-intensive Research Initiative of South Africa
DSBD	Department of Small Business Development
DST	Department of Science and Technology
DTPS	Department of Telecommunications and Postal Services
ECD	Early Childhood Development
EDD	Economic Development Department
EDP	Entrepreneurial Discovery Process
EQMS	Enterprise Quality Management Software
FSGDS	Free State Provincial Growth and Development Strategy
FTE	Full-time Equivalent
GCI	Global Competitive Index
GCI	Global Cybersecurity Index
GDED	Gauteng Department of Economic Development
GDP	Gross Domestic Product
GEM	Global Entrepreneurship Monitor

Acronym	Definition
GERD	Gross Expenditure on Research and Development
GGDA	Gauteng Growth and Development Agency
GII	Global Innovation Index
GNI	Gross National Income
HDI	Historically Disadvantaged Institution
HDI	Human Development Index
HDRO	Human Development Report Office
HEMIS	Higher Education Information Management System
HFCT	Hydrogen and Fuel Cells Technologies
HIV	Human Immunodeficiency Virus
HSRC	Human Sciences Research Council
ICT	Information and Communication Technology
IDC	Industrial Development Corporation
IEP	Integrated Energy Plan
IIU	Industrial Innovation Unit
IP	Intellectual Property
IPAP	Industrial Policy Action Plan
IPR	Intellectual Property Right
IRP	Integrated Resource Plan
ITU	International Telecommunication Union
LIIS	Limpopo Integrated Innovation Strategy
MBAC	Minerals Beneficiation Action Plan
MTSF	Medium-term Strategic Framework
NACI	National Advisory Council on Innovation
NAM	National Association of Manufacturers
NDP	National Development Plan
NFF	New Funding Framework
NGO	Non-governmental Organisation
NMISA	National Metrology Institute of South Africa
NMU	Nelson Mandela University
NPO	Non-profit Organisation
NRDS	National Research and Development Strategy
NRF	National Research Foundation
NSI	National System of Innovation

Acronym	Definition
NWU	North West University
ODA	Office of Digital Advantage
OECD	Organisation of Economic Cooperation and Development
OEM	Original Equipment Manufacturer
OTA	Office of Technology Assessment
PBR	Plant Breeders Right
PDI	Previously Disadvantaged Individual
PIC	Public Investment Corporation
PICC	Presidential Infrastructure Coordinating Commission
PPP	Public-private Partnership
R&D	Research and Development
RDI	Research, Development and Innovation
RDP	Reconstruction and Development Programme
RIMS	Revenue Information Management System
SABS	South African Bureau of Standards
SAEON	South African Environmental Observation Network
SAMRC	South African Medical Research Council
SANBI	South African National Biodiversity Institute
SANEDI	South African National Energy Development Institute
SARB	South African Reserve Bank
SARIR	South African Research Infrastructure Roadmap
SARS	South African Revenue Service
SAVCA	Southern African Venture Capital and Private Equity Association
SDG	Sustainable Development Goal
SEDA	Small Enterprise Development Agency
SET	Science, Engineering and Technology
SFP	Seed Fund Programme
SGI	Small Grain Institute
SII	South African Innovation Index
SIP	Strategic Integrated Project
SKA	Square Kilometre Array
SME	Small and Medium Enterprise

Acronym	Definition
SMME	Small, Medium and Micro Enterprises
SNC	Stellenbosch Nanofiber Company
SPI	Social Progress Index
SPII	Support Programme for Industrial Innovation
SSE	Substantive Search and Examination
STI	Science, Technology and Innovation
STISA	Science, Technology and Innovation Strategy for Africa
SU	University of Stellenbosch
TB	Tuberculosis
TBP	Technology Balance of Payment
TDF	Technology Development Fund
TEA	Total Early-stage Entrepreneurial Activity
The dti	Department of Trade and Industry
THRIP	Technology and Human Resources for Industry Programme
TIA	Technology Innovation Agency
TIMSS	Trends in Mathematics and Science Study
TVC	Technology Venture Capital
TYIP	Ten-year Innovation Plan
UCT	University of Cape Town
UJ	University of Johannesburg
UKIIF	UK Innovation Investment Fund
UKZN	University of KwaZulu-Natal
UNCTAD	United Nations Conference on Trade and Development
Unisa	University of South Africa
UP	University of Pretoria
UPOV	International Union for the Protection of New Varieties of Plants
USA	United States of America
USPTO	United States Patent and Trademark Office
UWC	University of the Western Cape
VOPI	Vegetable and Ornamental Plants Institute
WHO	World Health Organisation
Wits	University of the Witwatersrand
WRC	Water Research Commission

FOREWORD BY THE NACI CHAIRPERSON

On behalf of the National Advisory Council on Innovation (NACI), I am delighted to present the 2017 report on South African Science, Technology and Innovation (STI) Indicators.

The draft new White Paper on STI proposes that NACI provide hindsight, insight and foresight to help the National System of Innovation (NSI) to build scientific excellence and innovation capacity, with the ultimate aim of reducing poverty, unemployment and inequality. NACI and the DST-NRF Centre of Excellence in Scientometrics and STI Policy begun work on developing a monitoring and evaluation framework and system for the NSI, which will involve engagement with all key actors.

The STI Indicators Report is part of our current contribution to building the monitoring, evaluation and learning capability necessary for assessing the state of the NSI. It draws from the recently finalised Innovation Scorecard Framework, which was developed following broad consultation. This publication introduces new elements, covering, for instance, provincial and local innovation systems.

The STI Indicators Report identifies some challenges, as well as areas in which progress has been made. In 2017, South Africa ranked 39 out of 127 countries in business and innovation sophistication, a sub-index of the Global Competitiveness Index. Research and development investment, as a percentage of gross domestic product, increased to 0.8 in 2015/16, slightly up from the 0.77% recorded in 2014/15. However, this is still far from the target of 1.5% in 2019.

The venture capital industry plays a significant role in catalysing and growing technological entrepreneurship, especially for new high-growth start-ups. According to the 2017 survey of the Southern African Venture Capital and Private Equity Association, captive government funds, at 39%, were proportionally the largest source of funding for all the active deals invested, followed by independent funds at 35%.

The NSI human capital pipeline remains constrained. NACI continually monitors and comments on the percentage of Grade 12 learners who obtain 50% or more in Mathematics and Physical Science. For Mathematics, this percentage has been fluctuating for over a decade, from 18.1% in 2008 to 11.8% in 2015.

There is good progress in the number of women university graduates in science, engineering and technology (SET) disciplines. However, the proportion of women is below par at doctoral level (43% in 2015). In 2015, most of these degrees were in health and related clinical sciences (58%), life sciences (58%), education (52%) and agricultural sciences (50%). The number of women obtaining doctoral qualifications in disciplines like engineering, mathematics, statistics, and computer and information science is still low. The transformation challenge remains, and all NSI actors need to consider what they can do to address it.

The NACI Council and Secretariat are confident that all NSI stakeholders, including policy makers, the private sector and non-governmental organisations, will find this STI Indicators Report informative. We hope that it will also serve as a source of recognition of the work done so far, and an inspiration for further efforts to build the NSI.

Prof Cheryl de la Rey
Chairperson: National Advisory Council on Innovation

1. EXECUTIVE SUMMARY

The adoption of the South African Innovation Scorecard Framework by the National Advisory Council on Innovation (NACI) in 2016/17 provides a framework for the analysis of the state of science, technology and innovation (STI) in South Africa. This framework (Figure 1.1) categorises STI activities into three components: the public sector's enabling activities, firm-level innovation activities, and the economic and social outputs of innovation.

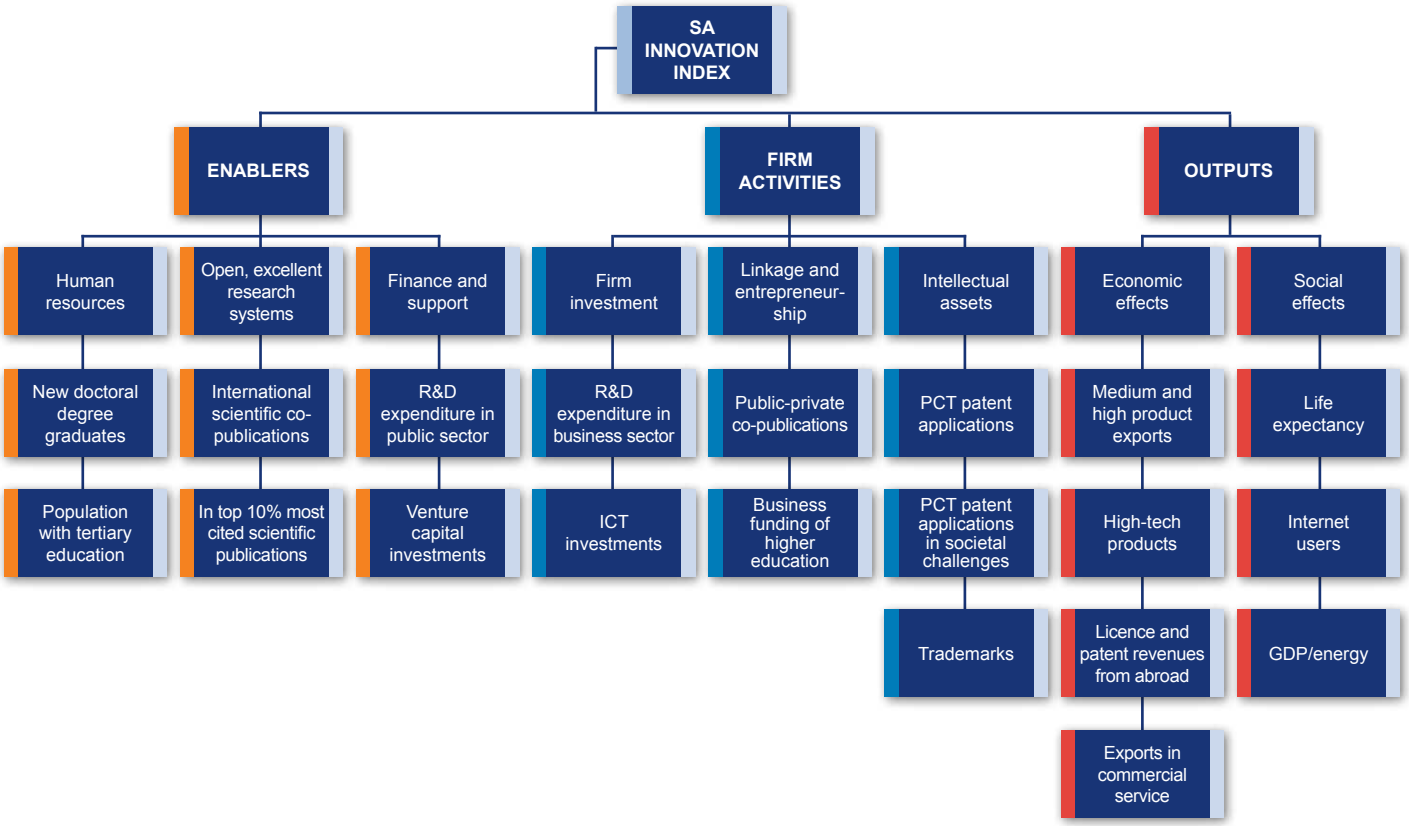


Figure 1.1: *South African Innovation Index (SII)*

The enablers incorporated into this report include STI human capital, knowledge generation, and STI funding and support. One of the key policy questions concerns the slow pace of absorption of black graduate researchers into the private sector. This report shows that there is a low supply of doctoral qualifications for females in disciplines such as engineering, mathematics and statistics, and computer and information sciences. Only 18% of doctoral degrees in engineering were awarded to female graduates in 2015. In terms of race, there is a limited supply of black doctoral graduates in disciplines such as life sciences and engineering. The recommendation for strengthening research capacity at historically disadvantaged institutions (HDIs) partly addresses this high-end skills supply challenge.

The firm-level innovation activities incorporated in this report are investments, linkages and entrepreneurship, as well as recent developments in the South African intellectual property right (IPRs) regime. On investments, government's contribution to business expenditure on research and development (BERD) is shown to be low and lacking an appropriate coordination mechanism for a coherent response to the prioritisation and funding of research and development (R&D) by various government entities. However, government is shown to contribute significantly to the South African venture capital industry, which is good news for innovation and technology commercialisation in small and medium enterprises (SMEs).

The innovation output pillar incorporates both the economic and social effects of innovation. The economic outcome indicators that are included in this report are the technology balance of payments and contribution of each sector to the gross value addition of the country. It is shown that high-technology exports remain low, with the country relying heavily on imported high-technology products. The high-technology industries in which the country is seriously underperforming are those of automatic data-processing machines, sound-recording apparatus, electrical and electronic goods, as well as medicinal products and pharmaceuticals. As industrial policy relies heavily on STI capabilities to transform the country into a knowledge-driven economy, a recommendation is made to strengthen the linkages between industrial policy and STI policy.

The inequality that is prevalent in South Africa appears to be a hindrance to achieve an inclusive society, which ought to be characterised by wellbeing and quality of life. With regard to the Social Progress Index (SPI), the country ranks higher in opportunity and foundations of wellbeing than in basic human needs. This stands in contradiction to the quality of life frameworks, which postulate that the basic human needs (nutrition, shelter, health, safety, sanitation and water) should be prioritised above other wellbeing priorities. The poor state of the health system is shown to be the main contributor to a lack of progress in the provision of basic needs of life.

This report also analyses selected key issues in STI policy, such as the implications of the Fourth Industrial Revolution (Industry 4.0) for South Africa, public-sector innovation, and local or regional systems of innovation. It does this by looking at innovation activities in the nine provinces of South Africa.

The analysis of the global competitiveness of South Africa, especially in respect of entrepreneurship, shows that there is a need for government to be innovative in easing the burden of doing business in South Africa; hence the incorporation of a recommendation for improving public-sector innovation in support of starting a business, handling insolvencies and saving on tax administration. This report discusses some public-sector innovations that have been showcased by the Centre for Public Sector Innovation (CPSI). Information and communication technologies (ICTs) provide an opportunity to enhance public-sector innovation. As the country is planning to embrace Industry 4.0, the recommendation in this report is to adopt the Fourth Industrial Revolution from the perspective of developing countries.

2. CURRENT TRENDS

2.1 LOCAL TRENDS IN SCIENCE, TECHNOLOGY AND INNOVATION

The role of STI in catalysing South Africa's development outcomes is well articulated in various documents, such as government's delivery agreements, the 2014–2019 Medium-term Strategic Framework (MTSF), the 1996 White Paper on Science and Technology, the 2002 National Research and Development Strategy (NRDS), the 2008 Ten-year Innovation Plan (TYIP) and sector-specific STI strategies. The National Development Plan (NDP), a blueprint for the long-term development of the country, also recognises the important role of STI.

Table 2.1 shows government's 14 targeted outcomes in the 2014–2019 MTSF and the impact of indicators or delivery plans that are related to STI. Some innovation-related outcomes (for example outcomes 1, 4, 5 and 7) are directly linked to the mandate of the Department of Science and Technology (DST) and its agencies. Other outcomes, such as Outcome 2 (health), are driven by other government departments. This is in line with the unpublished 2004 Strategic Management Model of the South African STI that defines the coordination of three types of STI: long-term STI conducted by the DST, sector-specific STI conducted by other government departments, and scientific and technological services.

For Outcome 1 (quality basic education), NACI continuously monitors and comments on the percentage of Grade 12 learners who obtain 50% or more in Mathematics and Physical Science. For Mathematics, this percentage has been oscillating for over a decade between a high of 18.1% in 2008 and a low of 11.8% in 2015.

The low percentage of learners passing Grade 12 Mathematics with 50% or more does not come as a surprise, based on the low scores obtained by South African Grade 9 learners in the 2015 Trends in Mathematics and Science Study (TIMSS): 372 against an MTSF target of 361 in 2015 and 401 by 2019. Mathematics is an important foundation for STI-related careers as it enables logical reasoning. Some notable initiatives that government is putting in place to improve Mathematics results are teachers' professional development and regular annual national assessments (to be replaced by the triennial National Integrated Assessment Framework).

Table 2.1: *Government outcomes and STI-related impact indicators*

OUTCOME	DESCRIPTION	STI-RELATED DELIVERY IMPACT INDICATORS/ACTIONS
1.	Quality basic education	Increased number and percentage of Grade 12 learners achieving 50% or more in Mathematics and Physical Science; increase in average score obtained by Grade 8 learners in Mathematics in TIMSS
2.	A long and healthy life for all South Africans	Increase in life expectancy at birth
3.	All the people of South Africa are and feel safe	Establishing a fully functional Centre of Competence for Cybersecurity; establishing a fully functional Incubational Cybersecurity Hub
4.	Decent employment through inclusive economic growth	Employment creation (including rural areas); reduction in official unemployment rate; increase in R&D investment as a percentage of gross domestic product (GDP)
5.	A skilled and capable workforce to support an inclusive growth path	Increase in the number of qualified artisans; increase in the number of university graduates in engineering sciences, human and animal health, and natural and physical sciences
6.	An efficient, competitive and responsive economic infrastructure network	Additional South African coal and gas enabled for energy production; increased broadband penetration; reduction of internet costs; increased public and private ICT investments

OUTCOME	DESCRIPTION	STI-RELATED DELIVERY IMPACT INDICATORS/ACTIONS
7.	Comprehensive rural development and land reform	Reduction in the percentage of households vulnerable to hunger; reduction in the percentage of the population living in poverty; reduction in the rural unemployment rate
8.	Sustainable human settlements and improved quality of household life	–
9.	Responsive, accountable, effective and efficient local government system	–
10.	Environmental assets and natural resources that are well protected and continually enhanced	Reduced emissions of total greenhouse gases; percentage increase in biomass stock levels; reduced vulnerability and risk associated with climate change impacts
11.	Create a better South Africa and contribute to a better and safer Africa in a better world	Increased foreign direct investment; increased value-added exports
12.	An efficient, effective and development-oriented public service	Service delivery quality and access improved and enabled through ICT
13.	An inclusive and responsive social protection system	–
14.	Nation building and social cohesion	–

On the health front, the country is showing some notable progress in making use of innovation and technology to improve health. According to the 2016/17 annual report of the South African Medical Research Council (SAMRC), the SAMRC funded 30 innovation and technology projects during that financial year, which were directed at developing new diagnostics, devices, vaccines and therapeutics. The country has a challenge to overcome the burden of diseases such as Human Immunodeficiency Virus (HIV)/Acquired Immune Deficiency Syndrome (AIDS) and tuberculosis (TB). HIV/AIDS and TB are among the leading causes of death in South Africa.[1]

According to the 2017 Global Cybersecurity Index (GCI), the country's commitment to cybersecurity is ranked 58th out of 193 International Telecommunication Union (ITU) member countries. Three categories are used to classify the ITU member states, based on the GCI: initiating stage (countries that have started to make commitments to improve cybersecurity), maturing stage (countries that have developed complex commitments and engage in cybersecurity programmes and initiatives) and leading stage (countries that demonstrate a high commitment to the five pillars of the index: legal, technical, organisational, capacity building and cooperation). South Africa is still in the maturing stage, far behind some African countries such as Mauritius (ranked 6th) and Egypt (ranked 14th), who are in the leading stage.

The key areas of cybersecurity improvement in South Africa that are recommended in the 2017 GCI report are the setting of cybersecurity standards for organisations and professionals, the establishment of cybersecurity metrics, the acceleration of cybersecurity R&D programmes, the provision of incentives for cybersecurity and the strengthening of cybersecurity cooperation agreements (bilateral, multilateral and interagency partnerships). The National Cybersecurity Hub, under the umbrella of the Department of Telecommunications and Postal Services (DTPS), has been established at the Council for Scientific and Industrial Research (CSIR) to serve as a central point for collaboration between industry, government and civil society on all cybersecurity-related incidents in South Africa.

The STI-related delivery plans for Outcome 4 (decent employment through inclusive economic growth) include an increase in R&D expenditure to 1.5% of GDP by 2019; the implementation and regular review of the Industrial Policy Action Plan (IPAP) in terms of its impact on growth, employment, investment, output, exports and African regional development; the development, implementation and regular review of the Agricultural Policy Action Plan (APAP) in terms of impact on growth, employment, rural incomes, investment, output, exports and African regional development; and the development, implementation and regular review of the Minerals Beneficiation Action Plan (MBAC) in terms of its impact on growth, employment, rural incomes, investment, output, exports and African regional development.

1 https://pmg.org.za/committee-meeting/22198/

Despite the introduction of the R&D Tax Incentive Programme – a 150% R&D expenditure deduction incentive for the private sector in respect of qualifying R&D activities – the gross expenditure on R&D (GERD) remains low at 0.8% of GDP. DST is exploring different mechanisms that can be utilised to increase R&D expenditure. These include the recent Cabinet-approved R&D budget-coordinating mechanism. There is consensus that a substantial increase in R&D expenditure should come from industry, with a conducive investment environment created by government's R&D and innovation funding instruments. IPAP has been an important instrument that coordinates the support and funding programmes of the Department of Trade and Industry (the dti) for industry. All the dti's funding programmes need to cover the areas under IPAP, an example of which is the Technology and Human Resources for Industry Programme (THRIP) that was recently transferred from the National Research Foundation (NRF) to the dti.

APAP is a programmatic response to key policy documents such as the NDP and MTSF (outcomes 4, 7 and 10). The NDP sees agriculture as having the potential to create close to a million new jobs by 2030 through the expansion of hectares under irrigation, better land usage in communal areas, the support of commercial agriculture sectors and regions that have the highest potential for growth and employment, as well as support for job creation in upstream and downstream industries.

Skills and human capital are necessary to support an inclusive growth path, which is embodied in Outcome 5. DST recently published the Human Capital Development Strategy for Research, Innovation and Scholarship to address the following main challenges: the low rate of production of research students, under-representation of black and female South African students in research degrees and careers, the need to promote and steer R&D and training activities, especially within domains and disciplines closely linked to technological innovation, the relatively low number of active and productive R&D workers, and the low level of support and coordination of productive partnerships between universities and research councils and across different government departments.

South Africa is undertaking several responsive infrastructure projects, primarily through the National Infrastructure Plan, driven through the Presidential Infrastructure Coordinating Commission (PICC). The 18 Strategic Integrated Projects (SIPs) that are being pursued through the PICC are in the areas of energy, water and sanitation, social infrastructure, knowledge infrastructure, regional integration, geographically focused SIPs and spatial SIPs. The two knowledge SIPs are the expansion of access to communication technology and support of the Square Kilometre Array (SKA) and MeerKAT projects.

Through the 2016 National Integrated ICT Policy White Paper, the DTPS seeks, among other issues, to ensure universal service and access to ICT services and infrastructure, to encourage ICT innovation and fair competition, to enable ICT convergence and to promote a digital society. The DST and its agencies are also contributing to the ICT infrastructure through initiatives such as the Data-intensive Research Initiative of South Africa (DIRISA) and the Office of Digital Advantage (ODA). The recently launched South African Research Infrastructure Roadmap (SARIR) seeks to mobilise research infrastructure investment in scientific domains such as energy, humans and society, health, biology and food security, earth and environment, and materials and manufacturing.

The efforts of the electricity production energy sector in adapting and mitigating against climate change and high carbon dioxide emissions are coordinated through the National Integrated Energy Plan (IEP) (a roadmap of the future energy landscape for South Africa that guides future energy infrastructure investment and policy development) and the Integrated Resource Plan (IRP) (a living document that directs the expansion of the electricity supply over the given period). One of the electricity production technologies that is being pursued through these plans is in respect of the development of wind and solar energy. Although such technology has proven to be vital in reducing reliance on coal energy, the challenge of renewable energy technology is the variability of the energy supply that is not suitable for maintaining base load energy.

The DST is implementing the National Hydrogen and Fuel Cells Technologies (HFCT) R&D and Innovation Strategy, which has the potential to enable the use of HFCT as the energy storage solution for solar and wind energy. The University of the Western Cape (UWC) demonstrated several hydrogen energy storage devices, although the focus is directed towards domestic and automotive applications. The 2016 IEP takes note of the ambitions of the DST on HFCT. It envisages potential applications such as the stand-alone 1 kW to 20 kW power systems for the electrification of municipalities and operations that are too far from the nearest grid, back-up power systems for residential and commercial buildings, storage systems for excess renewable energy during off-peak times and Combined Heat and Power (CHP) units for residential buildings.

2.2 GLOBAL TRENDS IN SCIENCE, TECHNOLOGY AND INNOVATION

This section provides a brief background and analysis of how South Africa is ranked across the different indices in respect of STI. It provides useful information for international comparisons and, in particular, gauges how well or badly South Africa is faring. The indices covered include the Global Innovation Index (GII), the Global Competitiveness Index (CCI), the Global Entrepreneurship Monitor (GEM) and the Human Development Index (HDI).

2.2.1 Global Innovation Index

The GII provides detailed metrics about the innovation performance of 127 countries and economies around the world. Its 81 indicators explore a broad vision of innovation, including political environment, education, infrastructure and business sophistication. The overall GII score is the average of the Innovation Input and the Innovation Output sub-index scores. The Innovation Input sub-index comprises five input pillars that capture elements of the national economy that embody innovative activities: institutions, human capital and research, infrastructure, market sophistication and business sophistication. The Innovation Output sub-index provides information about outputs that are the result of innovative activities within the economy: knowledge and technology outputs, and creative outputs.

Table 2.2 shows that South Africa's ranking on the GII dropped slightly from 54th (out of 128 countries) in 2016 to 57th (out of 127 countries) in 2017. This reverses the improvement achieved in the 2016 GII. At sub-index level, both the Innovation Efficiency Ratio and the Innovation Output sub-index improved slightly, while the Innovation Input sub-index slipped slightly from 47th in 2016 to 49th in 2017. A major cause of concern for South Africa in respect of innovation inputs has to do with human capital and research (from 55th to 60th position) and institutions (from 46th to 54th position).

Table 2.2: *Trends in South African ranking on the GII*

	2012	2013	2014	2015	2016	2017
GII ranking	**54**	**58**	**53**	**60**	**54**	**57**
Number of participating countries	**141**	**142**	**143**	**141**	**128**	**127**
Innovation Efficiency Ratio	**116**	**99**	**93**	**94**	**99**	**97**
Innovation Input	**45**	**51**	**47**	**54**	**47**	**49**
Institutions	39	44	44	43	46	54
Human capital and research	103	102	70	75	55	60
Infrastructure	79	83	84	89	85	75
Market sophistication	13	16	18	23	17	21
Business sophistication	55	71	68	73	56	57
Innovation Output	**73**	**71**	**63**	**61**	**71**	**69**
Knowledge and technology outputs	61	79	62	58	63	65
Creative outputs	86	68	70	76	77	78

Source: GII reports

The deterioration on the human capital and research pillar simply reflects the improvement in other countries' research and education systems, as none of the individual indicators triggered a cause for concern.

On the institutions pillar, a major driver for the drop in ranking is the deterioration in the business environment sub-pillar, from 38th in 2016 to 58th in 2017. In 2017, there was a reduction in the percentage of respondents from the Executive Opinion Survey that perceive South Africa as having sufficient mechanisms for ease of starting a business, resolving insolvency and paying taxes.

On a positive note, South Africa ranks much higher on the institutions pillar relative to other Brazil, Russia, India, China and South Africa (BRICS) countries, as well as the other two large economies in Africa: Egypt and Nigeria (Table 2.3). Some notable challenges are the low rankings of the Innovation Output and Innovation Efficiency Ratio sub-indices. The areas that require some improvement insofar as Innovation Input is concerned are those of infrastructure, human capital and research, as well as business sophistication.

Table 2.3: Benchmarking of GII rankings, 2017

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	RUSSIA	EGYPT	NIGERIA
GII ranking (out of 127)	**57**	**69**	**22**	**60**	**45**	**105**	**119**
Innovation Efficiency Ratio	**97**	**99**	**3**	**53**	**75**	**81**	**102**
Innovation Input	**49**	**60**	**31**	**66**	**43**	**106**	**118**
Institutions	54	91	78	92	73	121	123
Human capital and research	60	50	25	64	23	82	112
Infrastructure	75	57	27	73	62	93	111
Market sophistication	21	74	28	39	60	107	94
Business sophistication	57	43	9	55	33	120	118
Innovation Output	**69**	**80**	**11**	**58**	**51**	**97**	**119**
Knowledge and technology outputs	65	85	4	38	45	93	119
Creative outputs	78	83	26	85	62	97	102

Source: GII reports

2.2.2 Global Competitiveness Index

The GCI measures national competitiveness, defined as the set of institutions, policies and factors that determine the level of productivity of an economy, which, in turn, sets the level of prosperity that the economy can achieve. It combines 114 indicators that capture concepts that matter for productivity and long-term prosperity. These indicators are grouped into 12 pillars: institutions, infrastructure, macro economic environment, health and primary education, higher education and training, goods market efficiency, labour market efficiency, financial market development, technological readiness, market size, business sophistication, and innovation. These pillars are, in turn, organised into three sub-indices: basic requirements, efficiency enhancers, and innovation and sophistication factors.

Alarmingly, South Africa dropped 14 places on the 2017 GCI, from 47th in 2016 to 61st in 2017. This is the largest year-on-year decline since 2008, and followed slight improvements in 2015 and 2016 (Table 2.4). All three sub-indices contributed to this drop, although the efficiency enhancers sub-index dropped the most (from 35th place in 2016 to 52nd place in 2017). The two pillars that stand out as a cause for concern for the efficiency enhancers sub-index are financial market development (from 11th in 2016 to 44th in 2017) and goods market efficiency (from 28th in 2016 to 54th in 2017). The former reflects growing concern about the tentacles of corruption and state capture, which began to penetrate the financial sector.

Table 2.4: Trends in South African ranking on the GII

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
GCI ranking	**45**	**45**	**54**	**50**	**52**	**53**	**56**	**49**	**47**	**61**
Number of participating countries	**107**	**130**	**132**	**125**	**141**	**148**	**144**	**140**	**138**	**137**
Basic requirements	**69**	**77**	**79**	**85**	**84**	**95**	**89**	**85**	**84**	**92**
Institutions	46	45	47	46	43	41	36	38	40	76
Infrastructure	48	45	63	62	63	66	60	68	64	61
Macro economic environment	63	68	43	55	69	95	89	85	79	82
Health and primary education	122	125	129	131	132	135	132	126	123	121
Efficiency enhancers	**35**	**39**	**42**	**38**	**37**	**34**	**43**	**41**	**35**	**52**
Higher education and training	57	65	75	73	84	89	86	83	77	85
Goods market efficiency	31	35	40	32	32	28	32	38	28	54
Labour market efficiency	88	90	97	95	113	116	113	107	97	93

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Financial market development	24	5	9	4	3	3	7	12	11	44
Technological readiness	49	65	76	76	62	62	66	50	49	54
Market size	23	24	25	25	25	25	25	29	30	30
Innovation and sophistication factors	**36**	**39**	**43**	**39**	**42**	**37**	**37**	**36**	**31**	**39**
Business sophistication	33	64	38	38	38	35	31	33	30	37
Innovation	37	41	44	41	42	39	43	38	35	39

Source: World Economic Forum

The deterioration in financial market development is not a surprise in the context of slow economic growth and a decline in business confidence. According to the GCI reports, the factors that contribute to financial market development deterioration include the soundness of banks, regulation of securities exchanges, local equity market financing, and the availability and affordability of financial services.

The basic requirements, health and primary education pillar is still ranked very low (121st out of 137 countries) despite minor incremental improvements in ranking from 2013. Major challenges for health are the incidence of TB and its impact on business. HIV/AIDS prevalence remains high, and that has an impact on life expectancy at birth. Infant mortality also remains high. South Africa is making some positive reforms in primary education as the global ranking on quality of primary education and primary education enrolment rate is on the rise.

The negative impact of the state of health in South Africa on global competitiveness is clearly visible in Table 2.5, although Nigeria also experiences a similar challenge. Nigeria shoulders 10% of the global disease burden, and its main challenge is maldistribution of the available health sector workforce, and the increasing "brain drain" that results in a shortage of critically needed health professionals.

Table 2.5: *Benchmarking of GII rankings, 2017*

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	RUSSIA	EGYPT	NIGERIA
GCI ranking (out of 137)	**61**	**80**	**27**	**40**	**38**	**100**	**125**
Basic requirements	**92**	**104**	**31**	**63**	**48**	**106**	**136**
Institutions	76	109	41	39	83	64	125
Infrastructure	61	73	46	66	35	71	132
Macro economic environment	82	124	17	80	53	132	122
Health and primary education	121	96	40	91	54	87	136
Efficiency enhancers	**52**	**60**	**28**	**42**	**38**	**87**	**86**
Higher education and training	85	79	47	75	32	100	116
Goods market efficiency	54	122	46	56	80	90	96
Labour market efficiency	93	114	38	75	60	134	32
Financial market development	44	92	48	42	107	77	91
Technological readiness	54	55	73	107	57	94	112
Market size	30	10	1	3	6	25	26
Innovation and sophistication factors	**39**	**65**	**29**	**30**	**57**	**101**	**108**
Business sophistication	37	56	33	39	71	84	94
Innovation	39	85	28	29	49	109	112

Source: World Economic Forum

South Africa experiences a similar challenge of maldistribution of available health sector professionals, especially medical practitioners, as shown in Figure 2.1. Government is implementing several overseas training programmes in order to increase the number of medical practitioners, especially for rural areas.

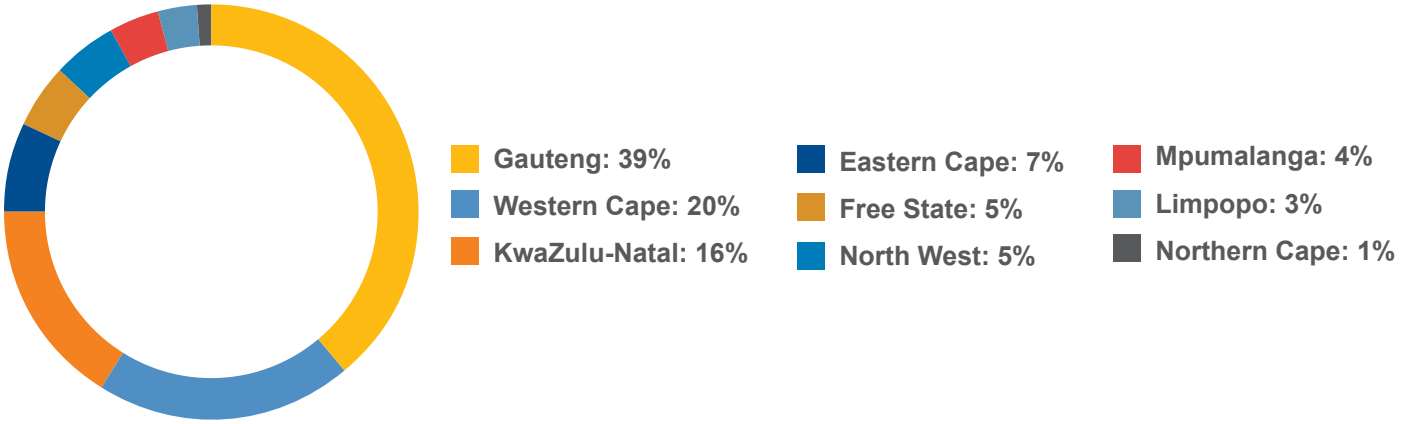


Figure 2.1: *Provincial distribution of medical practitioners in South Africa, 2016*

Source: Econex

2.2.3 Global Entrepreneurship Monitor

The GEM is the world's foremost study of entrepreneurship that looks at why some countries are more "entrepreneurial" than others. The GEM provides information, comprehensive reports and valuable insights, which greatly enhance the understanding of the entrepreneurial phenomenon. It is also the richest source of information on the subject, publishing a range of global, national and "special topic" reports.

The GEM looks at two elements in each economy: entrepreneurial behaviour and the attitudes of individuals, and national context and how that impacts on entrepreneurship. The central indicator of the GEM is the Total Early-stage Entrepreneurial Activity (TEA) rate, which measures the percentage of the adult population (18 to 64 years) that is in the process of starting or who has just started a business.[2]

Table 2.6 shows that South Africa has a very low rate of early-stage entrepreneurial activity (46th out of 65 participating countries in 2016). According to The World Bank's 2017 South Africa Economic Update report, South Africa's academic excellence and strong urban networks of entrepreneurs and opportunities in innovation are being stifled by an unconducive business environment, expensive trading costs, and low skills base. All of these are impeding the growth of start-ups, whereas in other countries, young, high-growth firms, known as "gazelles", are playing a leading role in innovation. Furthermore, it is disturbing to note how the slowdown in South Africa's growth performance since 2013 has been accompanied by a progressive decline in the country's TEA rate and ranking.

Table 2.6: *Trends in South African entrepreneurial activity among the adult population*

	2008	2009	2010	2011	2012	2013	2014	2015	2016
TEA rate	7.8	5.9	8.9	9.1	7.3	10.6	7.0	9.2	6.9
TEA world ranking	23	35	27	29	22	35	53	38	46
Number of participating countries	43	54	59	54	69	67	70	60	65

Source: 2016/17 South African Report (Global Entrepreneurship Monitor)

Table 2.7 shows that there is a proportionately higher early-stage entrepreneurial activity in South Africa for those with some form of post-secondary education, with an 11.9% TEA rate in 2016, compared with those with lower levels of education. This is high compared to that of those with no more than a basic education (4.6%), and even those who have completed secondary education but have not received tertiary education (7.4%). This is similar to trends in China

2 Global Entrepreneurship Monitor (2017) "2016/17 South African Report"

and India, although in Brazil, the TEA rate is distributed uniformly for those with basic and secondary education, and is relatively low for those with post-secondary education. Even so, the actual TEA rates in Brazil are much higher than in South Africa. Only Russia has lower values. This is a function of the legacy of communism in that country.

Table 2.7: *Benchmarking of South African entrepreneurial activity phases, 2016*

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	RUSSIA
TEA rate	**6.9**	**19.6**	**10.3**	**10.6**	**6.3**
Male TEA rate	8.0	19.2	11.8	13.5	6.9
Female TEA rate	5.9	19.9	8.6	7.6	5.7
TEA rate with basic education	4.6	19.5	6.6	8.1	6.4
TEA rate with complete secondary education	7.4	20.5	11.2	11.3	2.8
TEA rate with post-secondary education	11.9	14.4	12.1	14.1	7.1
TEA rate with some experience of postgraduate education	-	22.9	18.5	6.1	-
Percentage of new entrepreneurs innovating with technology of less than five years	55.1	4.0	35.4	55.7	23.6
Established business ownership rate	**2.5**	**16.9**	**2.5**	**7.5**	**5.3**
Male established business ownership rate	3.8	19.6	8.5	5.7	6.0
Female established business ownership rate	1.2	14.3	6.4	3.4	4.6
Percentage of established entrepreneurs innovating with technology of less than five years	53.2	4.0	38.5	40.4	24.0
Discontinuation of businesses rate	**4.5**	**4.6**	**4.5**	**3.5**	**2.1**

Source: 2016/17 Brazil Report (Global Entrepreneurship Monitor)

The percentage of new entrepreneurs innovating with technology of less than five years is very high in South Africa (55.1%) as compared with other BRICS countries other than India. It is exceptionally high relative to the 4.0% of Brazil. Indeed, the country has a high potential to produce "gazelles". The Department of Small Business Development (DSBD) recently launched the National Gazelles Programme, a national SME business growth acceleration programme to develop a new generation of successful South African entrepreneurs. The TEA rate is higher among males than among females in South Africa, as is also the case for other BRICS member countries, except Brazil (Figure 2.2).

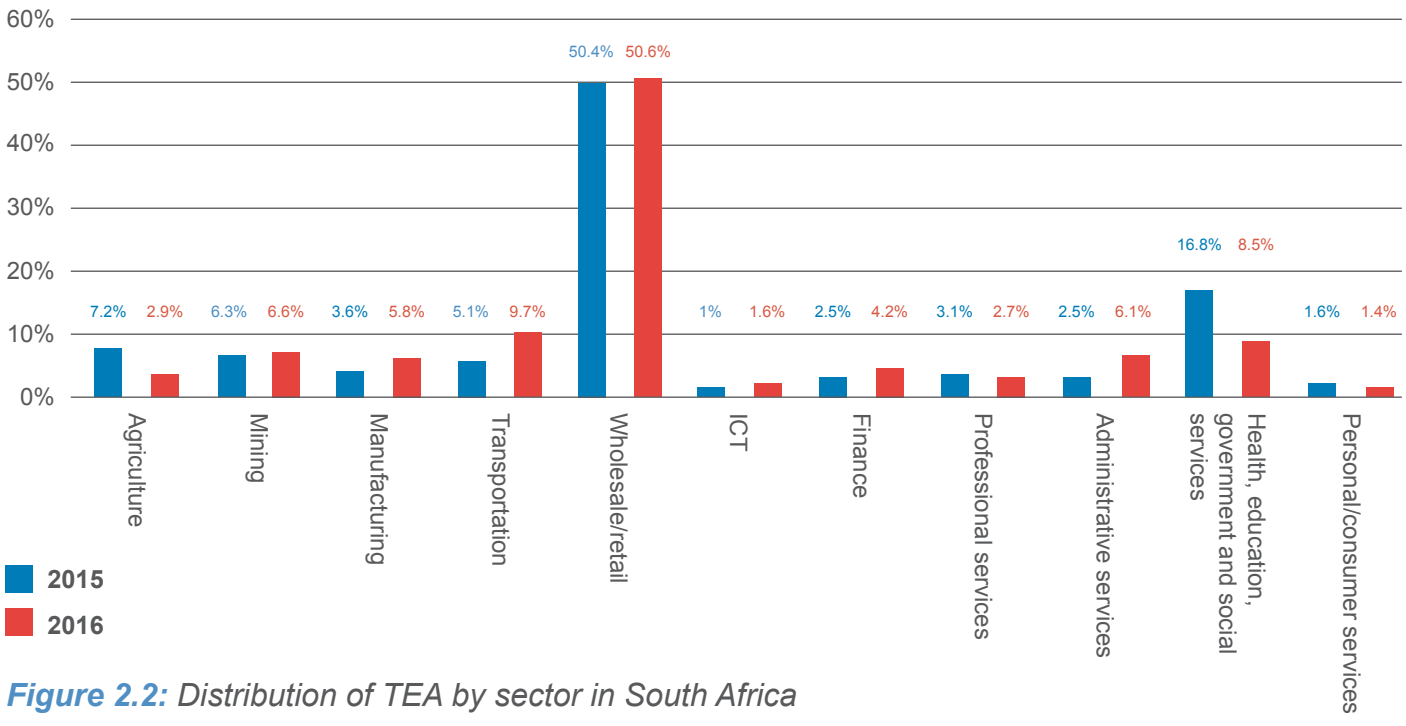


Figure 2.2: *Distribution of TEA by sector in South Africa*

Source: 2016/17 South African Report (Global Entrepreneurship Monitor)

Most early-stage entrepreneurial activities in South Africa are concentrated at the wholesale/retail sector of the economy (50.6% in 2016), followed by transportation (9.7%) and health, education, government and social services (8.5%). The latter dropped significantly from 16.8% in 2015 as government battled to contain its spending in order to limit the expansion of its budget deficit and public debt to placate credit ratings agencies.

The established business ownership rate for both males and females is very low in South Africa (3.8% and 1.2% of the adult population respectively in 2016) as is the case with China. In contrast, Brazil has a high rate of established business ownership (16.9%). This might explain the low usage of new technologies by both established and new entrepreneurs in that country.

Established businesses typically suffer from a "lock-in" on current competencies. Their dominance can stifle the innovativeness of new businesses. For both South Africa and India, new entrepreneurs have a slightly higher appetite for new technologies than established businesses. Again, this highlights the importance of start-ups within a country's innovation ecosystem. The deterioration with respect to the ease of doing business in South Africa is highlighted by a relatively high rate of business discontinuation (4.5% in 2016) in relation to India (3.5%) and Russia (2.1%).

2.2.4 Human Development Index

The HDI is a composite index that measures the average achievement in key dimensions of human development: a long and healthy life, knowledge and a decent standard of living. The health dimension is assessed by life expectancy at birth, while the education dimension is measured by means of years of schooling for adults aged 25 years and over, and expected years of schooling for children of school-entering age. The standard of living dimension is measured by gross national income (GNI) per capita.

The HDI was created to emphasise that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. However, it does not reflect adequately on issues such as inequalities, poverty, human security, and empowerment. The Human Development Report Office (HDRO) offers other composite indices as a broader proxy of some of the key issues of human development, inequality, gender disparity and poverty. The South African HDI value is increasing, albeit slightly (Figure 2.3).

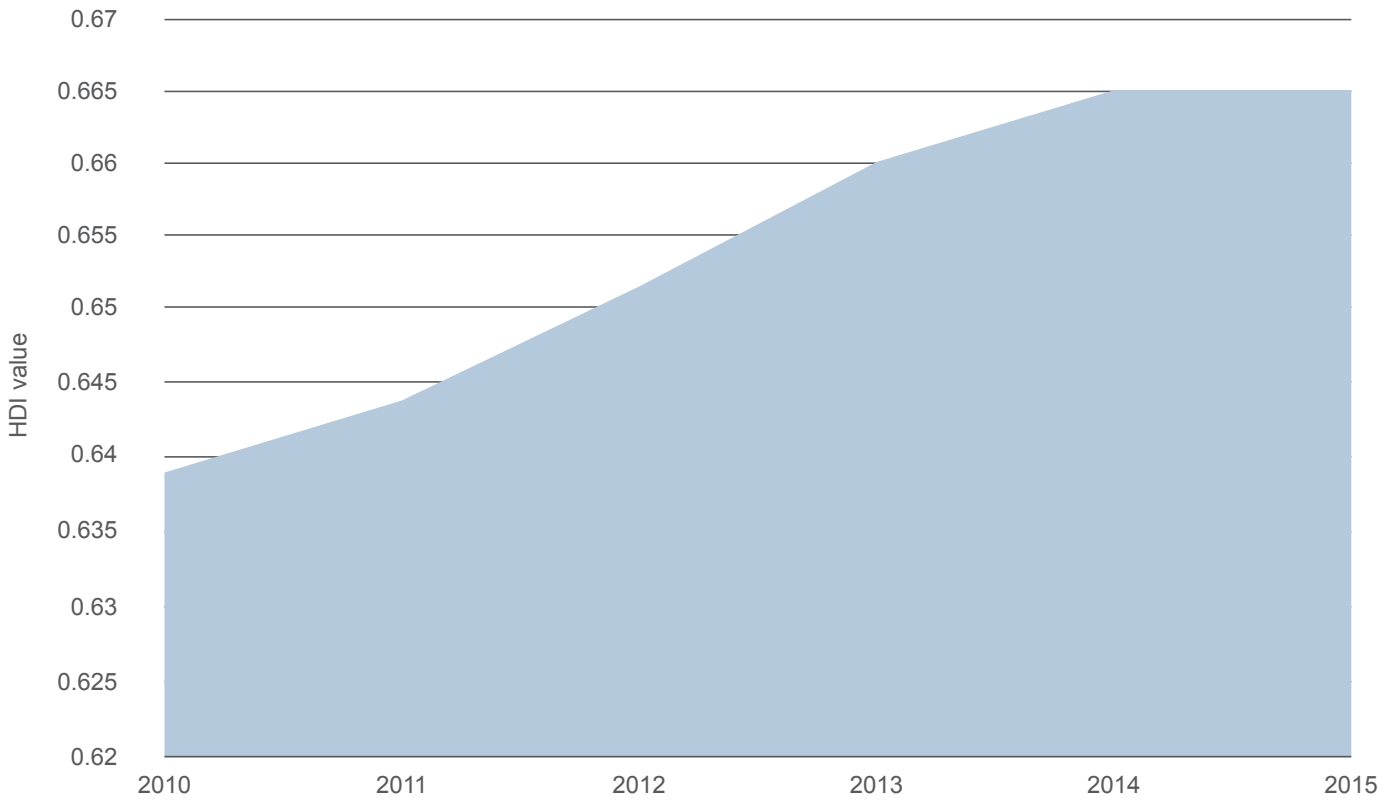


Figure 2.3: *Trends in the HDI for South Africa*

Source: 2016 Human Development Report (United Nations Development Programme)

In comparison with other BRICS member countries, the HDI value for South Africa is lower than that of Brazil, China and Russia, but higher than that of India (Table 2.8).

Table 2.8: *Benchmarking of the HDI, 2015*

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	RUSSIA	EGYPT	NIGERIA
HDI value	**0.666**	**0.754**	**0.738**	**0.624**	**0.733**	**0.691**	**0.527**
HDI world rank (out of 188)	**119**	**79**	**90**	**131**	**49**	**111**	**152**
Male HDI value	0.677	0.751	0.753	0.671	0.796	0.724	0.569
Female HDI value	0.651	0.754	0.718	0.549	0.809	0.640	0.482
Gender Development Index	0.962	1.005	0.954	0.819	1.016	0.884	0.847
GNI per capita rank	**89**	**78**	**84**	**127**	**49**	**104**	**128**

Source: 2016 Human Development Report (United Nations Development Programme)

A key contributing factor to South Africa's low HDI ranking is the weak health sector, as reflected by a relatively low life expectancy at birth. As a result, the HDI ranking for South Africa in 2015 was low in comparison to that of Egypt, although the global ranking of GNI per capita is higher. Due to the similar health sector challenges that are being experienced in Nigeria, the HDI value of Nigeria is lower than that of South Africa.

In terms of gender, the HDI value for males is slightly higher than that of females for South Africa, China, India, Egypt and Nigeria. Females have a relatively high quality of life in Brazil and Russia. Although females have a relatively higher life expectancy at birth, a low female GNI per capita rank has a negative impact on a country's HDI value. Brazilian females are active in both early-stage and established businesses. Among the BRICS member countries, Russia has the highest Gender Development Index, followed by Brazil. South Africa`s Gender Development Index is much lower than that of the other BRICS countries, except for India, but it is considerably higher than that of Nigeria.

3. ENABLERS: PUBLIC SECTOR ACTIVITIES

The public sector has a dual role of being the innovation performer and also the creator of the appropriate framework conditions for innovation in the private sector. Conducive framework conditions take on many forms, such as the enabling STI policy, relevant and appropriate strategies, establishing and maintaining strategic STI institutions to generate knowledge and de-risk technologies, the funding of R&D and innovation, developing STI human capital, establishing strategic partnerships and many more. As alluded to by the European Union, the innovation enablers are the basic building blocks that allow innovation to take place.[3]

3.1 SCIENCE, TECHNOLOGY AND INNOVATION HUMAN CAPITAL

The need to increase critical mass in STI is encapsulated in the 1996 White Paper on Science and Technology. The guiding principles of this policy document include issues such as investment in people as the productive and creative core of the economy, achieving equity through redress programmes aimed at undoing gender and race discrimination, research capacity development aimed at boosting HDIs and a lifelong learning approach. Table 3.1 shows various indicators of science, engineering and technology (SET) graduations at public universities. These STI human capital development indicators show some success in growing the SET base and promoting equity.

Table 3.1: *Public universities' SET graduation*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Total SET graduations ('000)	36.4	39.3	41.5	42.8	46.1	48.8	53.2	55.6	58.1
Percentage of SET graduations	29.5	29.9	28.7	27.6	28.6	29.6	30.1	30.6	30.7
Percentage of undergraduate SET graduations	28.8	29.4	28.9	27.9	28.7	29.4	29.4	30.0	30.3
Percentage of postgraduate SET graduations	26.4	27.6	29.4	28.7	28.9	29.1	27.7	28.5	29.3
Percentage of female SET graduations	49.2	49.5	49.3	49.1	49.4	49.4	50.0	50.2	50.6
Percentage of PDIs' total SET graduations	64.1	66.4	67.7	69.2	70.1	71.5	72.8	74.1	74.0

Source: Department of Higher Education and Training

3 europa.eu/rapid/press-release_MEMO-16-2487_en.pdf

The 1996 White Paper on Science and Technology inferred the process of individual capacity development as that of uplifting high-level skills, competencies, values and attitudes. Doctoral qualification is one of the proven methods of developing high-end skills. Table 3.2 shows a rising proportion of doctoral degrees awarded to Africans. Although this transformation is taking place at a slower pace than one might have liked to see, it should be embraced as deep transitions take longer periods to complete. The rising proportion of SET graduations by previously disadvantaged individuals (PDIs) (74.0% in 2015) gives hope of further redress of this ongoing concern.

Table 3.2: *Percentage distribution of SET doctoral degrees awarded by South African universities by race*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
African	27.89	33.68	36.29	37.93	38.49	42.05	43.74	47.81	46.64
Coloured	6.12	5.58	5.86	5.66	4.84	5.03	5.03	4.64	4.59
Indian	7.31	9.08	6.86	7.59	8.50	8.21	8.35	7.74	9.34
White	58.67	51.66	51.00	48.83	48.17	44.72	42.88	39.80	39.43

Source: Department of Higher Education and Training

The development of high-end skills should be matched with demand conditions of various sectors. It is therefore important to understand the nature of doctoral degrees awarded at South African universities. It can be deduced from the data shown in Table 3.3 that SET doctoral degrees awarded in 2015 accounted for no less than 49.9% of the total number of doctoral degrees awarded.

Table 3.3: *Distribution of doctoral degrees awarded by South African universities by classification of education subject matter*

	2010	2011	2012	2013	2014	2015
SET	**730**	**854**	**985**	**1 076**	**1 130**	**1 263**
Agricultural sciences	64	85	76	77	79	121
Computer and information sciences	30	42	41	49	55	51
Engineering	107	120	134	133	154	201
Health and related clinical sciences	111	155	186	216	244	253
Family ecology and consumer sciences	2	5	3	0	4	0
Life sciences	210	217	281	262	250	293
Physical sciences	166	176	204	255	255	258
Mathematics and statistics	33	41	45	66	67	66
Business and commerce	**106**	**129**	**162**	**159**	**193**	**260**
Education	**137**	**152**	**200**	**216**	**229**	**303**
Other humanities	**448**	**441**	**532**	**600**	**707**	**705**
Total	**1 421**	**1 576**	**1 879**	**2 051**	**2 258**	**2 530**

Source: Higher Education Management Information System (HEMIS) (Department of Higher Education and Training)

Most of these SET doctoral degrees have been awarded in the fields of life sciences, health sciences and related clinical sciences (43.2% in 2015), followed by physical sciences (20.4%), engineering (15.9%), agricultural sciences (9.6%), mathematics and statistics (5.2%) and computer and information sciences (4.0%).

In terms of rates of growth, SET doctoral degrees awarded have grown at an impressive average rate of 9.5%, although the variability from one year to the next is high. Between 2010 and 2015, the highest growth of doctoral degrees awarded was in health and related clinical sciences (127.9%), followed by mathematics and statistics (100.0%), agricultural sciences (89.1%), engineering (87.9%) and computer and information sciences (70.0%). The recent sharp increase in agricultural sciences doctoral degrees needs to be celebrated with caution, as, according to the Agricultural Research Council (ARC), the recent drought affected the trial periods for agricultural sciences postgraduate research students.[4]

Closer inspection of the distribution of doctoral degrees awarded to females according to the classification of education subject matter (CESM) categories (Table 3.4) reveals a serious shortage of females with high-end skills in disciplines such as engineering, mathematics and statistics, as well as computer and information sciences. Organisations such as the CSIR rely more on these disciplines, hence it has been difficult to increase the proportion of its female SET personnel with doctoral degrees.

Table 3.4: *Distribution of doctoral degrees awarded to female graduates at South African universities by classification of education subject matter, 2015*

	NUMBER OF FEMALE DOCTORAL GRADUATES	TOTAL NUMBER OF DOCTORAL GRADUATES	PROPORTION OF FEMALE DOCTORAL GRADUATES (%)
SET	**546**	**1 263**	**43**
Agricultural sciences	61	121	50
Computer and information sciences	16	51	31
Engineering	36	201	18
Health and related clinical sciences	146	253	58
Life sciences	170	293	58
Physical sciences	92	258	36
Mathematics and statistics	15	66	23
Business and commerce	**89**	**260**	**34**
Education	**159**	**303**	**52**
Other humanities	**325**	**705**	**46**
Total	**1 118**	**2 530**	**44**

Source: HEMIS (Department of Higher Education and Training)

During the 2016/17 financial year, the CSIR had 359 employees with doctoral qualifications (13.1%% of its staff), of which 24% was South African females and 34% was South African blacks.[5] The learning and growth targets that the CSIR did not achieve during 2016/17 were the number of SET staff, the number of black SET staff, the number of female SET staff and the number of SET staff with PhDs. The challenges experienced by the CSIR in terms of growing its transformed SET base include issues such as a poor macro economic environment and increasing competition from both local and international higher education institutions for the intake of relevant doctoral graduates.

4 http://www.arc.agric.za/Documents/Annual%20Reports/ARC%20Annual%20Report%202016-2017.pdf
5 https://www.csir.co.za/annual-report-201617

As shown by the CSIR as an analytical case study, there is a shortage of African graduates with doctoral degrees in disciplines such as life sciences (31% of total doctoral graduates in 2015) and engineering (37%). This is indicated in Table 3.5. As part of its transformation plan, the SAMRC seeks to increase the number of doctoral and postdoctoral researchers, and in 2016/17, it supported more than 60 doctoral students.[6]

The DST's Human Capital Development for R&D, Innovation and Scholarship proposes a range of interventions to increase the number and to improve the demographics of students enrolled for and graduating with master's and doctoral research degrees. These proposed interventions include a targeted increase in postgraduate student bursaries, the use of full-time postgraduate students to serve as research assistants to increase mentoring, tutoring and research capacity, the application of strong quality assurance measures to prevent the irresponsible massification of doctoral degrees, encouraging master's research students to register for doctoral studies upon graduation with a master's degree, improving the completion and throughput rate of doctoral degrees, and commissioning a study by DST to understand why fewer black South African students opt to enrol for master's and doctoral degrees than white South Africans do.

Table 3.5: *Distribution of doctoral degrees awarded to Africans at South African universities by classification of education subject matter, 2015*

	NUMBER OF AFRICAN DOCTORAL GRADUATES	TOTAL NUMBER OF DOCTORAL GRADUATES	PROPORTION OF AFRICAN DOCTORAL GRADUATES (%)
SET	**569**	**1 263**	**45**
Agricultural sciences	81	121	67
Computer and information sciences	27	51	53
Engineering	75	201	37
Health and related clinical sciences	107	253	42
Family ecology and consumer sciences	0	0	-
Life sciences	90	293	31
Physical sciences	145	258	56
Mathematics and statistics	35	66	53
Business and commerce	**131**	**260**	**50**
Education	**189**	**303**	**62**
Other humanities	**344**	**705**	**49**
Total	**1 233**	**2 530**	**49**

Source: HEMIS (Department of Higher Education and Training)

The R&D survey data on the employment of researchers gives a perspective regarding the demand conditions for researchers in various sectors (Table 3.6). A sector that lost the most jobs for researchers is the business sector, which recorded a loss of 1 545 full-time equivalent (FTE) jobs from 2008 to 2015. Science councils also experienced this loss of researchers' jobs, as alluded to by the CSIR. Research jobs have migrated towards the higher education sector,

6 http://www.mrc.ac.za/Media/2017/saMRCpresentationParliament.pdf

although government research laboratories and some non-governmental organisations (NGOs) also absorbed some of these researchers. This reorganisation hugely influences the overall type of research being conducted in the country, in favour of basic and applied research at the expense of experimental development.

Table 3.6: *Employment of researchers by sector (FTE)*

	BUSINESS	HIGHER EDUCATION	SCIENCE COUNCILS	GOVERNMENT	NGOs
2015	4 626.8	4 701.9	1 827.1	953.9	465
2014	4 636.2	5 097.7	1 765.4	970.0	506
2013	4 530.1	5 000.5	1 781.3	923.7	435
2012	4 555.9	4 700.6	1 697.1	1 091.4	394
2011	4 451.9	4 355.3	1 634.9	1 009.8	254
2010	4 804.0	3 613.7	1 777.3	874.2	250
2009	6 059.5	3 761.8	2 251.5	680.4	224
2008	6 172.0	3 643.5	2 246.5	805.0	262
2007	6 047.5	3 672.3	2 300.2	757.6	264

Source: National Survey of Research and Experimental Development (Human Sciences Research Council (HSRC) and DST)

Figure 3.1 shows the overall trends in the migration in the employment of researchers. A massive decline took place during 2010, but some recovery occurred in 2011 as universities absorbed the redundant researchers. Following such massive absorption of researchers, universities seem to have reached their full capacity since 2013, although there were also some signs of recovery within the business and science council sectors. The aspirations of the 1996 White Paper on Science and Technology on transformation are also being realised in terms of redress.

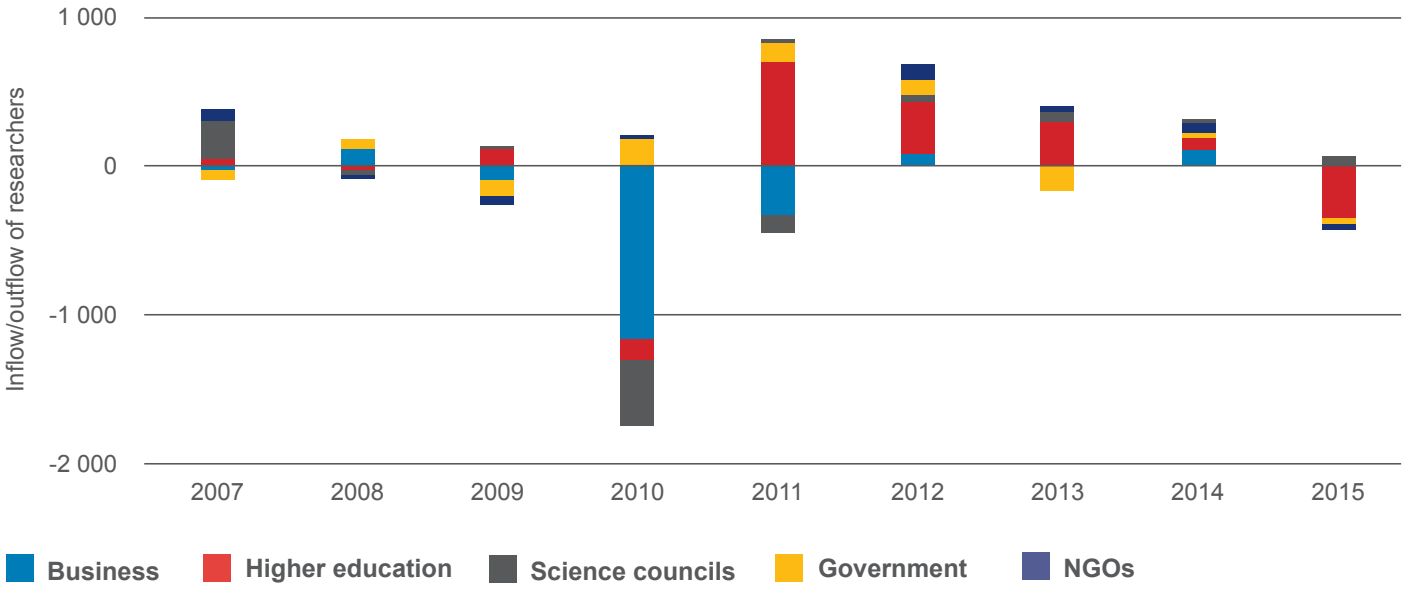


Figure 3.1: *Inflow/outflow of researchers per sector of employment (FTE)*

Source: National Survey of Research and Experimental Development (HSRC and DST)

Figure 3.2 shows that the proportion of African researchers is increasing steadily, whereas that of white researchers is declining. An increase in the supply of African master's and doctoral graduates in scientific disciplines such as engineering and life sciences can only accelerate this transformation project.

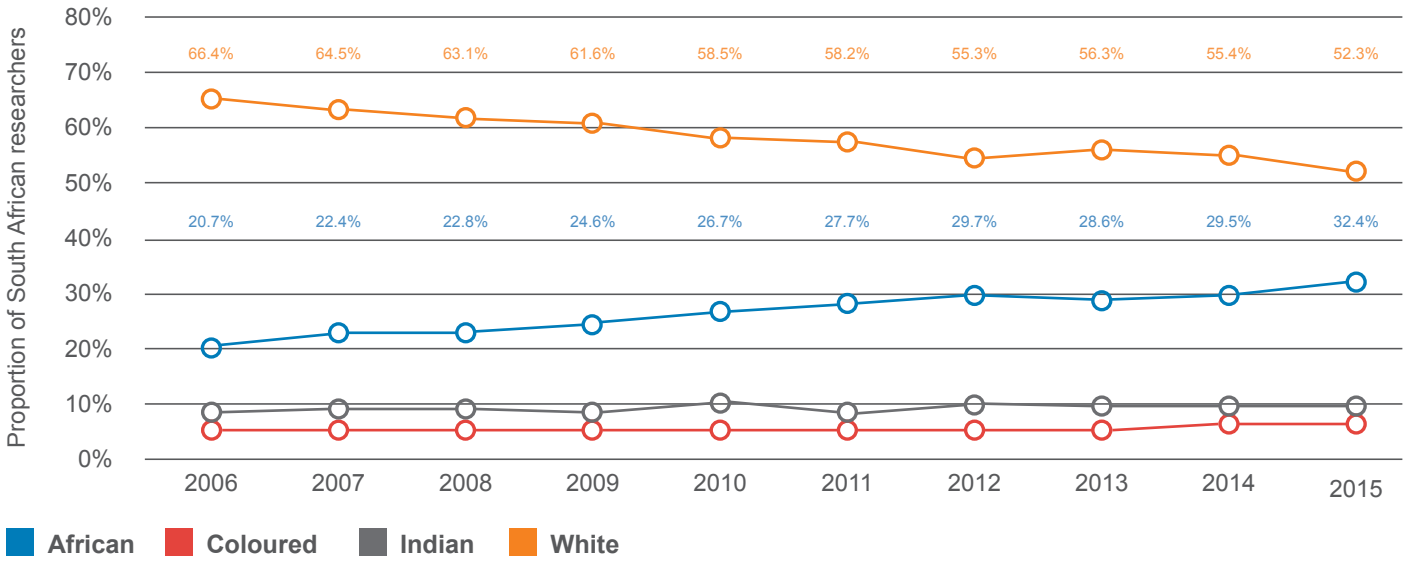


Figure 3.2: *Trends in the proportion of South African researchers per race*

Source: National Survey of Research and Experimental Development (HSRC and DST)

3.2 KNOWLEDGE GENERATION

Indicators based on research publications are probably the most often used in the assessment of research activities. The philosophy underlying the use of research publications as a measure of performance has been summarised as "for those who are working at the research front, publication is not just an indicator but, in a very strong sense, the end product of their creative effort".[7]

Quantitative assessments have a number of advantages. For example, they are repeatable and verifiable exercises. They are not dependent on the choice of experts and their opinions, which may vary as the choice of participants changes. Probably their most important advantage is that they allow for comparisons between different scientific disciplines and different countries. Both types of comparisons are not possible through peer review approaches as it is almost impossible to find peers with expertise in different scientific fields and knowledge of the research systems in different countries.

The Web of Knowledge of Thomson Reuters was used for this investigation. Figure 3.3 shows the number of publications with at least one South African author during the period 1995 to 2016. It is apparent that, since 2005, the number of South African publications has shown a rising trend.

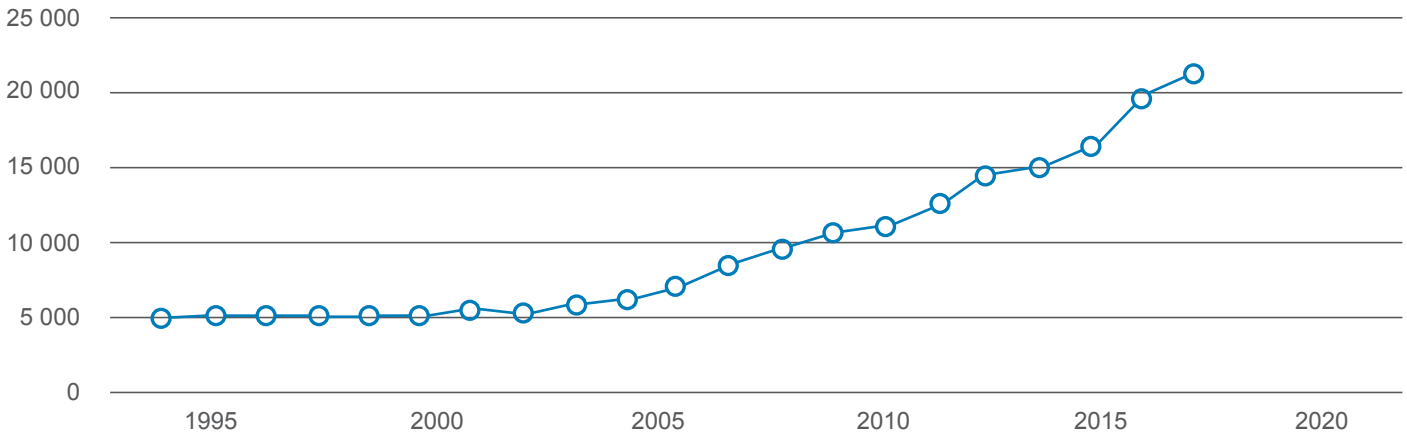


Figure 3.3: *South African publications, 1995–2016*

7 De Solla Price, D. (1975) "The productivity of research scientists", *Yearbook of science and the future*, Encyclopaedia Britannica, University of Chicago, Chicago, IL

There was an investigation into the effects of international collaboration in respect of the NRF researcher rating system and of journals added to the database during 2008 on the basis of the number of publications.[8] This investigation concluded that the New Funding Framework (NFF) for higher education institutions affects the number of publications. The NFF was published in terms of the Higher Education Act, Act No. 101 of 1997, in the *Government Gazette* (No. 1791) on 9 December 2003 and was implemented in the 2004/05 financial year. The NFF supports the higher education institutions (among others) financially according to their research outputs (number of publications and number of postgraduates). It is apparent that the incentive brought about the desired effect. This increase in South African scientific publications is driven partly by the increase in international research collaborations (Table 3.7).

Table 3.7: *South African scientific publications*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total scientific publications	**8 653**	**9 642**	**10 715**	**11 138**	**12 828**	**14 524**	**15 131**	**16 570**	**17 487**	**18 576**
Percentage of publications in top 1%	1.12	1.35	1.18	1.50	1.22	1.18	1.68	1.54	1.60	1.57
Percentage of publications in top 10%	9.73	10.37	9.37	10.43	9.45	9.16	10.34	10.28	9.72	9.15
Percentage of international collaborations	40.1	40.46	42.12	42.8	43.43	43.27	46.65	48.5	49.95	52.82
Percentage of industry collaborations	1.06	1.71	1.35	1.63	1.21	1.22	1.46	1.3	1.27	1.35

Source: Incites 2.0 (Clarivate Analytics)

About 53% of the publications with at least one author from South Africa were written in collaboration with researchers from other countries. This resulted in an increase in the quality of scientific output as the percentage of publications in the top 1% increased from 1.12% in 2007 to 1.68% in 2013. This was followed by a decrease to 1.57% in 2016. According to Clarivate Analytics,[9] the top 1% for scientific publications is significant as it is considered to be an indicator of research excellence. Scientific collaborations within industry are also on the increase, although this increase has taken place from a very low base of 1.06% in 2007.

Table 3.8 provides statistical information on the broad South African scientific disciplines for the period 1995–2016. It shows the number of publications produced with at least one South African author in each broad scientific field, the share of each discipline in the South African set of publications, the country's share of world publications in the particular field and the world ranking of South Africa in each field. South Africa is ranked 18th in the world in social sciences, and arts and humanities, 33rd in life sciences, 38th in physical sciences and 40th in technology.

Table 3.8: *Scientific disciplinary performance of South Africa 1996–2016*

	NUMBER OF PUBLICATIONS	SOUTH AFRICA'S SHARE (%)	WORLD SHARE (%)	SOUTH AFRICAN WORLD RANKING
Social sciences	31 651	13.9	0.80	18
Arts and humanities	8 842	3.9	0.33	18
Life sciences	103 441	45.4	0.63	33
Physical sciences	46 119	20.2	0.50	38
Technology	37 847	16.6	0.37	40

8 Pouris, A. (2012) "Scientometric research in South Africa and successful policy instruments", *Scientometrics* 91:317–325
9 https://tmsnrt.rs/2ji7iPR

Appendix 1 shows the most prolific countries in the broad scientific disciplines during the period 2010–2015. The tables reveal that the USA is on top of all the lists, with the exception of technology. In technology, the People's Republic of China bypassed the USA, and during the period 2011–2015, it was producing 23.1% of the world's publications in the field. South Africa ranked best proportionately in social sciences, and arts and humanities. Table 3.9 constitutes another representation of the performance of various scientific disciplines according to the Organisation of Economic Cooperation and Development (OECD)'s Frascati Manual classification.

Table 3.9: *Number of scientific publications per major research field*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Natural sciences	4 313	4 560	5 085	5 193	6 192	6 448	7 032	7 676	7 973	8 955
Engineering and technology	1 478	1 428	1 687	1 790	2 082	2 229	2 790	2 860	3 152	3 559
Medical and health sciences	2 473	2 806	2 905	3 125	3 299	3 900	4 211	4 923	4 849	5 131
Agricultural sciences	512	577	778	680	839	737	921	817	843	927
Social sciences	1 164	1 665	1 802	1 937	2 172	2 964	2 452	2 828	3 034	2 996
Humanities	1 269	741	693	727	820	762	851	901	1 012	1 015

Source: Incites 2.0 (Clarivate Analytics)

It should be noted that, in this classification, the biological/life sciences discipline is included in the natural sciences category. This trend in scientific outputs well resembles the trend of South African universities awarding doctoral degrees. Encouragingly, there has been a meaningful increase in the number of publications produced in all scientific fields in recent years.

The publication outputs of various public research institutions are shown in Table 3.10. The NRF's national research facilities (Hartebeesthoek Radio Astronomy Observatory, iThemba Labs, National Zoological Gardens of South Africa, South African Astronomical Observatory, South African Environmental Observation Network, South African Institute for Aquatic Biodiversity and the SKA South Africa) are leading with 733 Web of Science publications in 2016. This represents 39.0% of all publications by South African public research institutions in 2015.

The CSIR accounted for 25.3%, followed by the SAMRC (17.1%), ARC (10.3%), Human Sciences Research Council (HSRC) (7.1%) and the National Metrology Institute of South Africa (NMISA) (1.1%).

Table 3.10: *Number of scientific publications per public research institute*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CSIR	226	286	379	363	385	399	463	462	468	475
NRF	296	317	337	432	484	545	552	536	679	733
SAMRC	55	61	66	70	109	117	149	183	243	322
ARC	68	64	79	93	132	106	147	156	179	194
HSRC	47	76	79	87	92	119	104	121	106	134
NMISA	10	13	6	12	18	16	21	17	16	20

Source: Incites 2.0 (Clarivate Analytics)

Most university publications originate from the traditional universities (80.4% in 2016). The top five universities (University of Cape Town, University of the Witwatersrand, University of Pretoria, University of KwaZulu-Natal and University of Stellenbosch) account for 78.2% of the publications from traditional universities (Table 3.11).

The comprehensive universities accounted for 14.7% of publications in 2015, while the universities of technology accounted for only 4.8% of university publications.

Table 3.11: Number of scientific publications per type of university

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Traditional universities	**7 318**	**8 337**	**9 049**	**9 399**	**10 858**	**12 539**	**13 240**	**14 294**	**15 107**	**16 200**
University of Cape Town	1 744	1 882	1 978	2 093	2 303	2 609	2 749	3 027	3 021	3 264
University of the Witwatersrand	1 215	1 310	1 396	1 546	1 740	2 067	2 032	2 261	2 519	2 687
University of Pretoria	1 165	1 296	1 416	1 360	1 568	1 697	1 804	1 855	2 138	2 295
University of KwaZulu-Natal	898	1 150	1 184	1 144	1 477	1 662	1 953	2 118	2 108	2 242
University of Stellenbosch	1055	1 184	1 351	1 375	1 535	1 802	1 917	2 056	2 065	2 185
Other traditional universities	1241	1 515	1 724	1 881	2 235	2 702	2 785	2 977	3 256	3 527
Comprehensive universities	**677**	**828**	**1 082**	**1 151**	**1 611**	**1 824**	**1 838**	**2 173**	**2 677**	**2 968**
University of Johannesburg	266	309	434	462	708	856	844	1 039	1 265	1483
University of South Africa	191	233	243	254	295	375	452	494	686	738
Other comprehensive universities	220	286	405	435	608	593	542	640	726	747
Universities of Technology	**264**	**303**	**403**	**553**	**665**	**660**	**753**	**812**	**905**	**974**
Tshwane University of Technology	128	156	186	231	297	300	355	361	397	371
Other universities of technology	136	147	217	322	368	360	398	451	508	603

Source:Incites 2.0 (Clarivate Analytics)

3.3 SCIENCE, TECHNOLOGY AND INNOVATION FUNDING AND SUPPORT

This section describes the major organisations involved in funding R&D and innovation in the country, major funding instruments and recent changes in their modus operandi. Furthermore, the major funding instruments are described, and their advantages and shortcomings discussed. The following organisations are the major funding agencies in the country: the NRF, the Water Research Commission (WRC), the South African National Energy Development Institute (SANEDI) and the SAMRC.

3.3.1 National Research Foundation

The NRF was established in 1998 through the National Research Foundation Act (Act No. 23 of 1998). It is the largest South African research funding agency with total revenue of R4.1 billion during 2016. It has three primary income streams and one minor source of income:

- **Parliamentary grant:** This is utilised primarily to fund the programmes and operational activities of the NRF.
- **Ring-fenced funding:** This is received from the DST to fund specific projects.
- **Designated income:** This represents income for specific contract funding.
- **Other income:** This is represented by interest received on funds invested.

The NRF's income increased with 34% from the previous year (2015). This was attributed to a 114% increase in ring-fenced funding received for human capacity development (R357 million) and the SKA South Africa project (R339 million) from the DST. In tandem, the NRF's expenditures increased. The increase of 35% in total expenditure was composed as follows:

- The Innovation Honours, Master's and Doctoral programmes (R229 million)
- The South African Research Chairs Initiative (R125 million)
- The incentive programmes for rated researchers (R58 million)
- Competitive support – rated researchers (R63 million)
- Centres of Excellence (R30 million)
- Human resource development next-generation and emerging researchers (R59 million)
- Scarce Skills Fund (R54 million)

In aggregate, during 2016, the following amounts (in R'000) were spent:

Grants and bursaries	2 556 223
Programme, operating and other	665 296
Employees remuneration	577 904
Net capital expenditures	345 205

In more detail, the following programmes were supported:

Postgraduate Support	R904 million
Emerging and Established Researchers	R495 million
Strategic Investments (research chairs and centres)	R550 million
National Equipment Programme	R347 million

Among the facilities, the highest expenditures were for the SKA (R396 million) and iThemba Labs (R259 million). Important changes during the year include the following:

- During 2017, the NRF announced that it had changed the modus operandi of the incentive programme for rated researchers. As a result, approximately R116 million would not be distributed to rated researchers.
- The National Zoological Gardens was officially transferred from the NRF to the custodianship of the South African National Biodiversity Institute (SANBI) on 1 April 2017.
- In its annual report, the CEO of the NRF stated: "Over the five-year period from 2012 to 2017, the Parliamentary Grant has declined, year on year, in real terms by an average of 3% per year. The designated and earmarked allocation to the NRF has, however, increased in real terms over the same period. While this is welcome, these funds cannot be used for other important initiatives outside their designated purpose. To improve the long-term operational and financial sustainability of the organisation, it will be necessary for the designated and contract income to be included in the Parliamentary Grant". The NRF succeeded in getting additional flexibility in its operations. However, this may provide challenges to the DST as it will not have an easily available implementation agency.
- The distribution of funds to various activities indicates that there is a redirection towards the support of postgraduate students. While this is an important domain, the possible shortcomings from redirecting funds from other objectives, such as improved basic education and early childhood development, should be taken into consideration.

3.3.2 Water Research Commission

The WRC was established through the Water Research Act, Act No. 34 of 1971. Its primary functions have traditionally been to fund and steer South Africa's water research agenda, and to disseminate and effectively communicate research findings. More recently, the WRC was called on to also support the development of human capacity and skills, as well as lead technology, product and industry development. The WRC receives its funding from three sources: the Water Research Levy, leverage funding and other sources.

The Water Research Levy is its main source of revenue. It is levied in terms of the Water Research Act. The WRC receives its levies from three sources: the Rand Water Board, the Umgeni Water Board, and the Department of Water and Sanitation. It should be emphasised that the levies are proportional to water consumption. It can be argued that the approach is perverse as, during a drought, less water is consumed and more research is required. Water research funding will certainly be reduced, *ceteris paribus*. During 2015/16, the WRC received R200 million from water research levies and R61.0 million as leverage funding. Leverage funding refers to funding received from various sources for research purposes. During the year, R189.6 million was invested for R&D and R11.4 million for innovation and impact. In more detail, R&D funding was spent on the following categories:

Table 3.12: *The WRC's R&D expenditure according to various categories, 2015/16*

CATEGORY	EXPENDITURE (MILLION R)	PERCENTAGE
Water resource management	46 219	22
Water-linked ecosystems	25 984	13
Water use and waste management	52 651	26
Water utilisation in agriculture	29 790	15
Knowledge dissemination	11 400	6
Other levy-funded projects	177	1
Empowerment Fund	1 161	1
Other leverage-funded projects	33 666	17

It should be noted that South Africa is ranked 19th in the world in water research, while the country as a whole is ranked in the mid-30s according to research publications. It has been argued that the existence of a research agency (such as the WRC) brings the desired effect in improving the country's research capacity.[10]

South Africa's Water Research, Development and Innovation Roadmap 2015–2025 was published during 2015.[11] The vision of the roadmap is that the country is a "leader among middle income countries in the development and deployment of water management practices and technologies. It competes with leading countries in providing sustainable solutions". The roadmap develops seven plans under the following headings:

Water supply:

- Increase the ability to make use of more sources of water, including alternatives
- Improve the governance, planning and management of supply and delivery
- Improve the adequacy and performance of the supply infrastructure
- Run water as a financially sustainable business by improving operational performance

Water demand:

- Improve the governance, planning and management of demand and use
- Reduce losses and increase efficiency of productive use
- Improve the performance of pricing, monitoring, billing, metering and collection

The roadmap provides estimates of the resources that will be required to achieve the desirable objectives. The WRC currently investigates the benchmarks, with 2015 as the starting year.

3.3.3 South African National Energy Development Institute

SANEDI was established as a successor to the previously created South African National Energy Research Institute and the National Energy Efficiency Agency. The National Energy Act (Act No. 34 of 2008) gave effect to SANEDI's existence and provides for its primary mandate and specific responsibilities. The Act provides for SANEDI to direct, monitor and conduct energy R&D, and to undertake measures to promote energy efficiency throughout the economy.

SANEDI's mission is stated as follows: "accelerating the implementation of energy research and development, improving energy efficiency and increasing the uptake of renewable energy for the benefit of South Africa".[12] During 2015/16, SANEDI declared the following funding sources:

10 Jacobs, I.M., Pouris, A. and Naidoo, D. (2014) "A scientometric examination of the performance of water research in South Africa" *Water SA* 40(4)
11 Water Research Commission (WRC) (2015) "South Africa's Water Research, Development and Innovation Roadmap 2015–2025", WRC, Pretoria
12 South African National Energy Development Institute (SANEDI) (2016) "Annual Report 2015/16", SANEDI, Sandton

Table 3.13: *SANEDI's funding sources, 2015/16*

SOURCE	INCOME (R'000)	PERCENTAGE
National departments	72 861	14
International donors	19 790	4
Reconstruction and Development Programme (RDP) funding	182 672	36
Roll-over funding	227 080	44
Local partners	4 739	1
Other Income	5 088	1

It is interesting to note that the income from government departments was only R72.8 million. The administration costs were R43.7 million during the period. It is doubtful that the size of this funding can support the energy needs of the country. It has been argued that "this lack of research activity may have a number of adverse consequences for the economy. For example, it can be argued that the lack of expertise and independent advice (for example in the country's universities) may be partially the cause of the recent failure of Eskom to meet electricity demand in the country".[13]

3.3.4 South African Medical Research Council

The SAMRC's mandate is to improve the health and quality of life of all South Africans, and the research it conducts is based on the following six research programmes:

- Health Promotion and Disease Prevention
- Maternal, Child and Women's Health
- HIV, AIDS, TB and Other Communicable Diseases
- Health Systems Strengthening
- Public Health Innovation
- Biomedical Research

Research takes place in intramural and extramural units. Extramural research units are situated at higher education institutions and are supported by the SAMRC. During 2016/17, the SAMRC had a revenue of R937 million and other income of R6 million. Government grants and subsidies amounted to R576 million.

3.3.5 Technology Innovation Agency

The Technology Innovation Agency (TIA) was formed under the Technology Innovation Agency Act (Act No. 26 of 2008). TIA's mandate is to enable and support technological innovation across the economy. These goals are achieved by supporting the development and commercialisation of research outputs from higher education institutions, science councils, public entities and private research institutions.

The Parliamentary Grant increased by 13% from R342 million in 2014/15, to R385 million in 2015/16. Royalty income of R5 million was received from seven projects from various industries, such as ICT, health, mining and agriculture. Total other income was R35 million. Administrative expenditure was R47 million and employee costs amounted to R83 million. TIA's funding operates through three programmes: the Seed Fund Programme (SFP), the Technology Development Fund (TDF) and the Commercialisation Support Fund (CSF). The SFP was launched during 2013/14 with the objective of providing access to early-stage funding and support services. More specifically, the stated objective of the programme is to assist higher education institutions and small, medium and micro enterprises (SMMEs) to advance their research outputs and ideas to develop prototypes, proof of concept and business cases that could be used for further development. The SFP has two sub-programme models: the higher education SFP and the SMME SFP.

During 2015/16, TIA funded 101 projects totalling R44.9 million in the higher education SFP and five projects totalling R2.5 million in the SMME SFP. On average, each project received approximately R450 000 and the success rate was approximately 37%.

13 Pouris, A. (2016) "A bibliometric assessment of energy research in South Africa", *South African Journal of Science* 112(11/12)

4. FIRM ACTIVITIES IN SCIENCE, TECHNOLOGY AND INNOVATION

There are various models of firm-level innovation, each with its own successes and failures. The model of innovation that is adopted by the firm needs to reflect the country's framework conditions, as well as the other competitive drivers. The pillars adopted by NACI for firm-level innovation activities are firm investments, linkages and entrepreneurship, and intellectual assets.

4.1 INVESTMENTS

The wide range of business STI investments that are analysed in this section include expenditure on R&D, as well as venture capital activity. These two categories cover a broad range of the innovation value chain, from R&D to technology development and commercialisation.

4.1.1 R&D funding and expenditure in the business sector

The widely used indicator for business investment on technological innovation is BERD. As shown in Figure 4.1, BERD has been on a recovery mode since 2011 when measured in rand terms. The R13.8 billion BERD in 2015/16 represents 42.7% of GERD. However, this ratio has been on a decline. At the beginning of the global economic recession in 2008/09, BERD, as a percentage of GERD, was 58.6%. During 2013/14 and 2014/15, this ratio had fallen to 45.9% and 45.3% respectively, and by 2015/16, this ratio had declined to 42.7%.

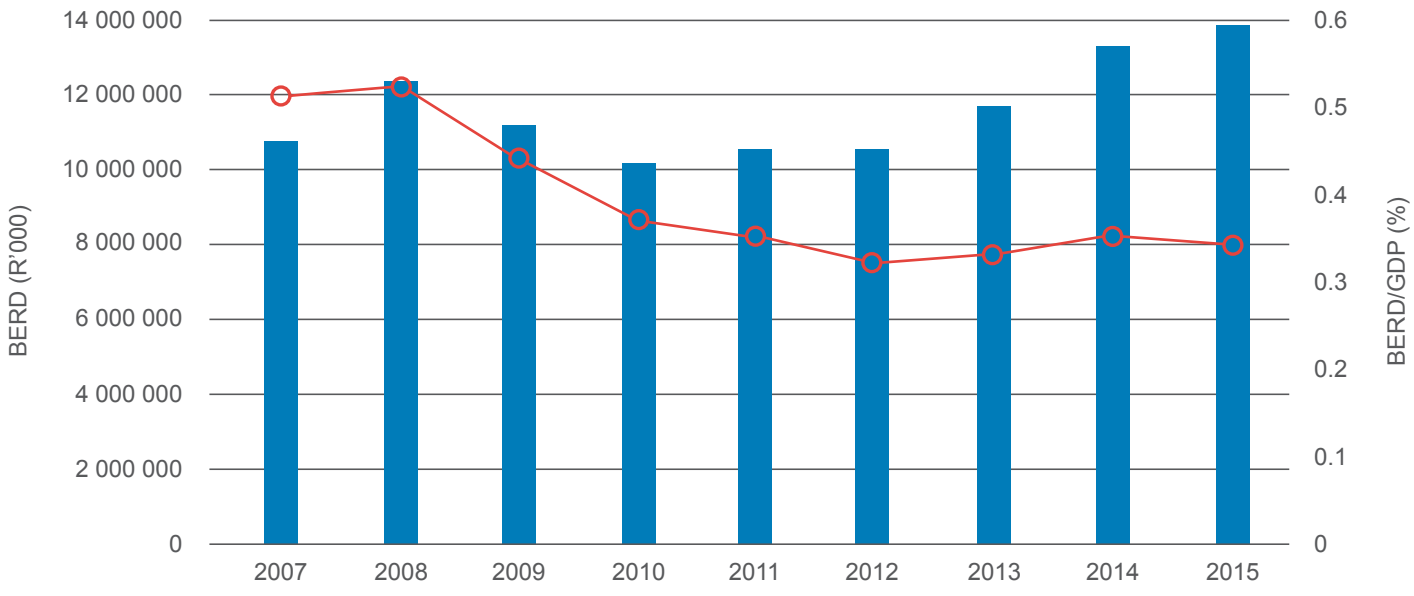


Figure 4.1: *Trends in business sector R&D expenditure*

Source: National Survey of Research and Experimental Development (HSRC and DST)

Although the business sector remains the largest R&D-performing sector in South Africa, the higher education sector is increasing its R&D expenditure at a higher pace in comparison to the business sector. Its share of R&D expenditure, as a percentage of GERD, increased from 19.4% in 2007/08 to 30.5% in 2015/16. The relatively low level of BERD is clearly demonstrated by the reduced BERD as a percentage of GDP (Figure 4.1). This places a huge strain on the country's ability to achieve the target of 1.5% R&D expenditure as a percentage of GDP.

The government has put various support programmes in place for business research and innovation to accelerate the level of technological innovation within the business sector. Two modes of funding are used by government: direct and indirect funding. The direct funding instruments include the dti's THRIP and the Support Programme for Industrial Innovation (SPII), DST's Industry Innovation Partnership (which incorporates the Sector Innovation Fund programme), TIA's SFP, TDF and CSF, the Industrial Development Corporation (IDC)'s Technology Venture Capital Fund, and the Small Enterprise and Development Agency (SEDA)'s Technology Transfer Fund.

Several reviews and evaluations have been done to assess the impact of these government support programmes of business R&D and innovation. Some of the criticisms include the small size of these funding instruments, the lack of prioritisation and the lack of coordination among them. Indeed, the R&D survey data supports these criticisms as there has been a relative decline in government funding of BERD, from a proportion of 27.3% in 2007/08 (R2.3 billion) to 9.2% in 2010/11 (R4.2 billion) and to 3.6% in 2015/16 (R0.5 billion).

Figure 4.2 shows that, during 2015/16, business funded about 82.4% of its own R&D expenditure (R11 billion), whereas foreign sources contributed 11.1% (R1.5 billion) and government contributed 3.8% of BERD (R523 million). There is an urgent need for dialogue between various government departments and agencies as to how to increase the support to business R&D and innovation, especially during this period of slow economic growth.

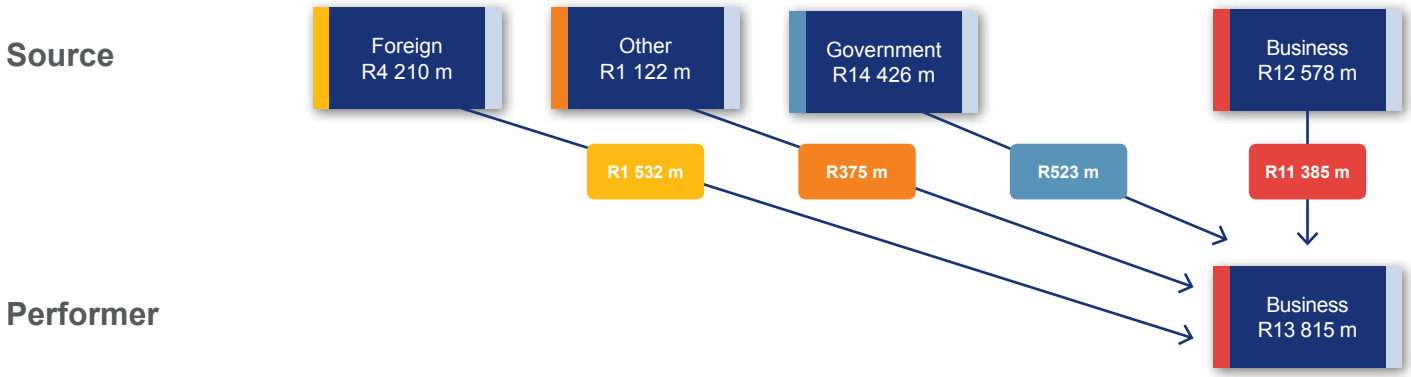


Figure 4.2: *Business sector funding sources and performance of R&D, 2015/2016*

Source: Adapted from National Survey of Research and Experimental Development (DST)

South Africa is not alone in these challenges, as demonstrated by the following conclusion of the UK's National Audit Office report on cross-government funding of R&D: "Government needs a coherent view of the UK's research strengths relative to other nations and analysis of funding in key areas of research, so that it can prioritise areas where activity is lagging behind and ensure the UK is investing in the right areas. While some of the more mature areas of research we examined have well-established arrangements to support coordination and collaboration between public-sector funders, some newer areas, including important emerging technologies and areas of national importance, currently require more effective leadership".[14]

The indirect business R&D and innovation funding instruments are the R&D Tax Incentive (Section 11D of the Income Tax Act) and the Venture Capital Company (Section 12J of the Income Tax Act). The R&D Tax Incentive was introduced in 2016 and allows for a 150% deduction of pre-approved R&D. According to National Treasury's 2017 Budget Review, the tax revenue foregone due to this incentive was R361 million, R340 million, R163 million and R34 million in 2011/12, 2012/13, 2013/14 and 2014/15 respectively. Tax revenue foregone as a percentage of BERD was 3.4%, 3.2%, 1.4% and 0.3% in 2011/12, 2012/13, 2013/14 and 2014/15 respectively.

14 https://www.nao.org.uk/report/cross-government-funding-of-research-and-development/

Note that the figures are revised annually as new information on new claims is recoded. In order to address the backlog on the pre-approval system, National Treasury is considering revising the aspects of the legislation that have created this complexity.[15] Furthermore, the Department of Planning, Monitoring and Evaluation is conducting a review of all tax incentives and grants to ensure that they are aligned with inclusive growth objectives.

Table 4.1 shows the areas of R&D expenditure for R&D tax incentive beneficiaries arranged by IPAP sectors. The pre-approval system that was introduced in October 2012 seems to have benefited the ICT sector as the electro-technical and ICT sector had a large share between October 2012 and February 2017 (30.7%). During a retrospective R&D deduction approval system (November 2006 to September 2012), a large share was directed at the upstream oil and gas sector (23.8%), followed by the chemicals, cosmetics, pharmaceuticals and plastics sector (19.9%).

Table 4.1: *Approved R&D tax incentive applications by IPAP sector*

IPAP SECTOR DESCRIPTION	R&D EXPENDITURE APPLICATIONS APPROVED BETWEEN NOVEMBER 2006 AND SEPTEMBER 2012 (IN R'000)	R&D EXPENDITURE APPLICATIONS APPROVED BETWEEN OCTOBER 2012 AND FEBRUARY 2017 (IN R'000)	CUMULATIVE (NOVEMBER 2006 TO FEBRUARY 2017) (IN R'000)	PERCENTAGE TOTAL CONTRIBUTION TO IPAP SECTORS
Upstream oil and gas	4 669 185	1 451 800	6 120 985	21.7%
Electro-technical and ICT	3 873 476	2 633 632	6 507 108	23.0%
Chemicals, cosmetics, pharmaceuticals and plastics	3 909 221	1 558 414	5 467 635	19.4%
Automotives, components, medium and heavy commercial vehicles	3 321 901	183 220	3 505 121	12.4%
Metal fabrication, capital and transport equipment sectors	1 217 985	1 069 190	2 287 175	8.1%
Business process services	1 172 476	53 789	1 226 265	4.3%
Aerospace and defence	497 888	694 092	1 191 980	4.2%
Agro-processing, linked to food security and food pricing imperatives	384 937	358 223	743 161	2.6%
Forestry, paper, pulp and furniture	256 300	545 547	801 847	2.8%
Advanced materials	243 761	-	243 761	0.9%
Nuclear	62 516	-	62 516	0.2%
Green and energy-saving industries	35 057	-	35 057	0.1%
Boat building	-	37 200	37 200	0.1%
Clothing, textiles, footwear and leather	355	2 300	2 655	0.0%
Total	**19 645 058**	**8 587 407**	**28 232 465**	**100.0%**

Source: 2015/16 R&D Tax Incentive Programme, report to Parliament (DST)

15 National Treasury (2018) "Budget Review"

Table 4.2 confirms the relatively large investment in R&D by the ICT sector (18.6% in 2015/16), although engineering sciences has the largest R&D expenditure (24.8%), albeit a declining trend. There are linkages to be made between BERD by research field, employment of researchers by the business sector and supply of doctoral graduates.

Table 4.2: *Proportion of BERD by research field*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
	PERCENTAGE								
Division 1: Natural sciences, technology and engineering	**96.5**	**96.5**	**96.4**	**95.6**	**95.5**	**86.3**	**82.9**	**82.6**	**82.9**
Mathematical sciences	1.6	1.5	1.6	1.1	2.0	1.4	1.8	1.6	0.9
Physical sciences	4.7	5.3	1.7	0.3	0.3	0.5	0.4	0.4	0.3
Chemical sciences	5.4	7.0	5.6	6.8	8.9	9.3	8.3	6.4	7.0
Earth sciences	0.9	0.8	0.8	1.1	0.9	1.0	0.9	0.9	0.7
Biological sciences	1.5	1.3	1.7	2.1	2.0	2.0	1.8	1.9	1.8
Information, computer and communication technologies	20.3	19.6	25.6	24.9	23.7	14.9	13.7	14.4	18.6
Applied sciences and technologies	14.7	13.6	11.4	11.3	8.6	8.2	6.9	7.2	6.5
Engineering sciences	30.1	31.7	29.7	27.5	26.3	26.8	26.3	26.7	24.8
Biological sciences	1.5	1.3	1.7	2.1	2.0	2.0	1.8	1.9	1.8
Agricultural sciences	2.9	2.4	2.9	3.7	4.5	4.2	5.0	5.0	4.9
Medical and health sciences	11.8	12.2	14.1	16.1	17.6	17.1	16.8	16.3	16.7
Environmental sciences	0.6	0.5	0.4	0.1	0.0	0.4	0.4	0.6	0.2
Material sciences	1.7	0.7	0.6	0.6	0.6	0.5	0.5	1.2	0.5
Marine sciences	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0
Division 2: Social sciences and humanities	**3.5**	**3.5**	**3.6**	**4.4**	**4.5**	**13.7**	**17.1**	**17.4**	**17.1**
Social sciences	3.5	3.5	3.5	4.4	4.5	13.7	17.1	17.4	17.1
Humanities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: National Survey of Research and Experimental Development (HSRC and DST)

Table 4.2 reflects the type of research areas that are in demand in the business sector. Since it has been shown that there is a low proportion of female doctoral graduates in fields such as engineering (18% in 2015), computer and information sciences (31%) and physical sciences (36%), it can be expected that there will be a supply shortage of female researchers in fields such as engineering sciences, ICT and chemical sciences. This can also explain the low proportion of female researchers in the business sector (38.7%, 39.6% and 39.3% in 2015/16, 2014/15 and 2013/14 respectively).

4.1.2 Venture capital investments

The venture capital industry plays a significant role in catalysing and growing technological entrepreneurship, especially for new high-growth start-ups. It is a useful vehicle for the commercialisation of technology, which includes university spin-offs. This is also true in South Africa, as demonstrated by venture capital investments by stage of the deal (Figure 4.3) in 2016. About 47% of the active funds under management were invested in start-up capital, with 4% being for seed funding.

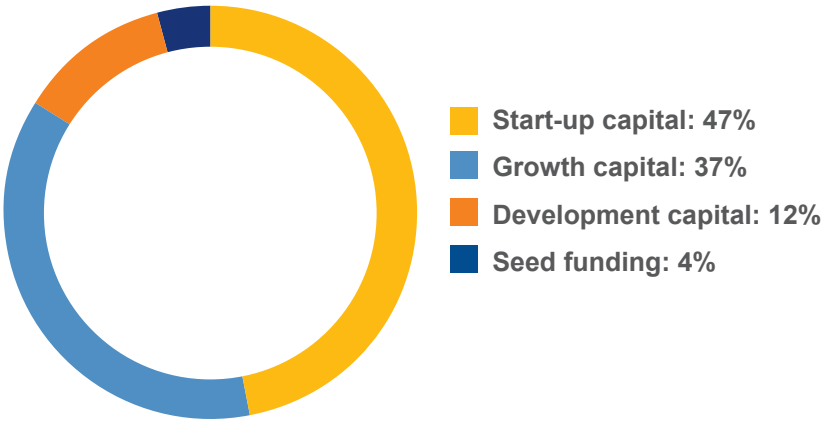


Figure 4.3: *Venture capital investments by stage of the deal, 2016*

Source: 2017 Venture Capital Survey (Southern African Venture Capital and Private Equity Association (SAVCA))

Figure 4.4 shows that government plays a significant role within the South African venture capital industry as it funded 39% of active funds under management in 2016, followed by independent fund managers (35%), corporate (15%), angel investors (6%) and other sources (5%).

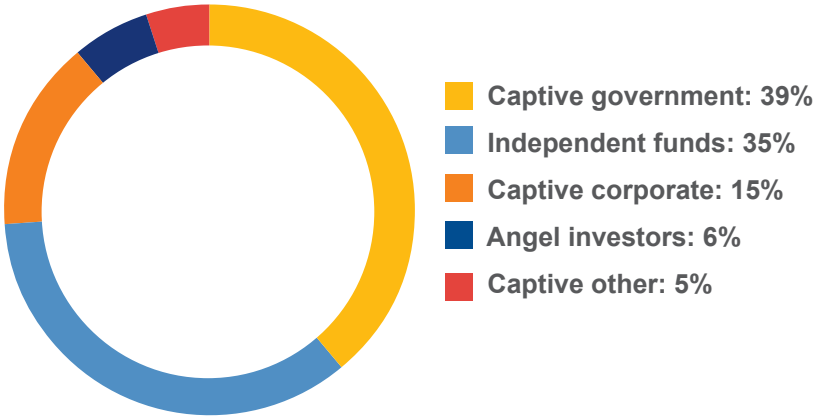


Figure 4.4: *Venture capital investments by type of fund manager, 2016*

Source: 2017 Venture Capital Survey (SAVCA)

According to the 2017 Venture Capital Survey, "government has invested R1.28 billion through three government-sponsored captive funds. As has been alluded to, the IDC has set up the Technology Venture Capital (TVC) Fund, which has an off-balance sheet fund of R130 million. This represents 10.2% of government's venture capital funds. The objective of the TVC Fund is "to provide funding and business support to small companies at early stages of commercialisation (not development) of innovative products, processes and technologies across all sectors which have the potential to make a significant developmental impact on the South African economy".[16]

Another aspect of government's venture capital platforms relates to the various instruments of the National Empowerment Fund that fall under the iMbewu, uMnotho, Rural and Community Development, and Strategic Projects funds. Under the Rural and Community Development Fund, there is a New Venture Capital Fund, a product aimed at assisting rural entrepreneurs, cooperatives and communities with equity contribution to establish sustainable new ventures in the agri-sector, including forestry, tourism and processing. The TIA Seed Fund disbursed R47.8 million via technology transfer offices for universities and R26.5 million via small business support organisations in 2016/17 (a total of R74.3 million).[17]

16 https://www.idc.co.za/home/idc-products/special-schemes/technology-venture-capital-fund.html
17 http://ventureburn.com/2017/09/tia-seed-fund/

The Public Investment Corporation (PIC), through its Isibaya Fund, has also set up a handful of funding instruments that support technology-based start-ups. These include a Fund of Funds, which is an indirect investment through experienced private-sector fund managers. In its previous government-supported private venture capital study, a greater use of a Fund of Funds was recommended as successful private fund managers can provide the necessary guidance and mentorship to techno-entrepreneurs.

Figure 4.5 shows the proportion of venture capital investments in various technology sectors. The Southern African Venture Capital and Private Equity Association (SAVCA) has summarised the extent of these venture capital investments in various sectors as follows: "deals involving the ICT sectors account for the largest portion of investments (30% of all deals concluded by number of deals and approximately 17% by value of deals), life sciences (biotechnology, health and medical devices) comprise a substantial component of the active portfolio (19% by number and approximately a quarter by value of all deals), predominantly held by captive government fund managers. Business and consumer services make up the third-largest component of active investments, totalling 16% by number and some 11% by value".[18]

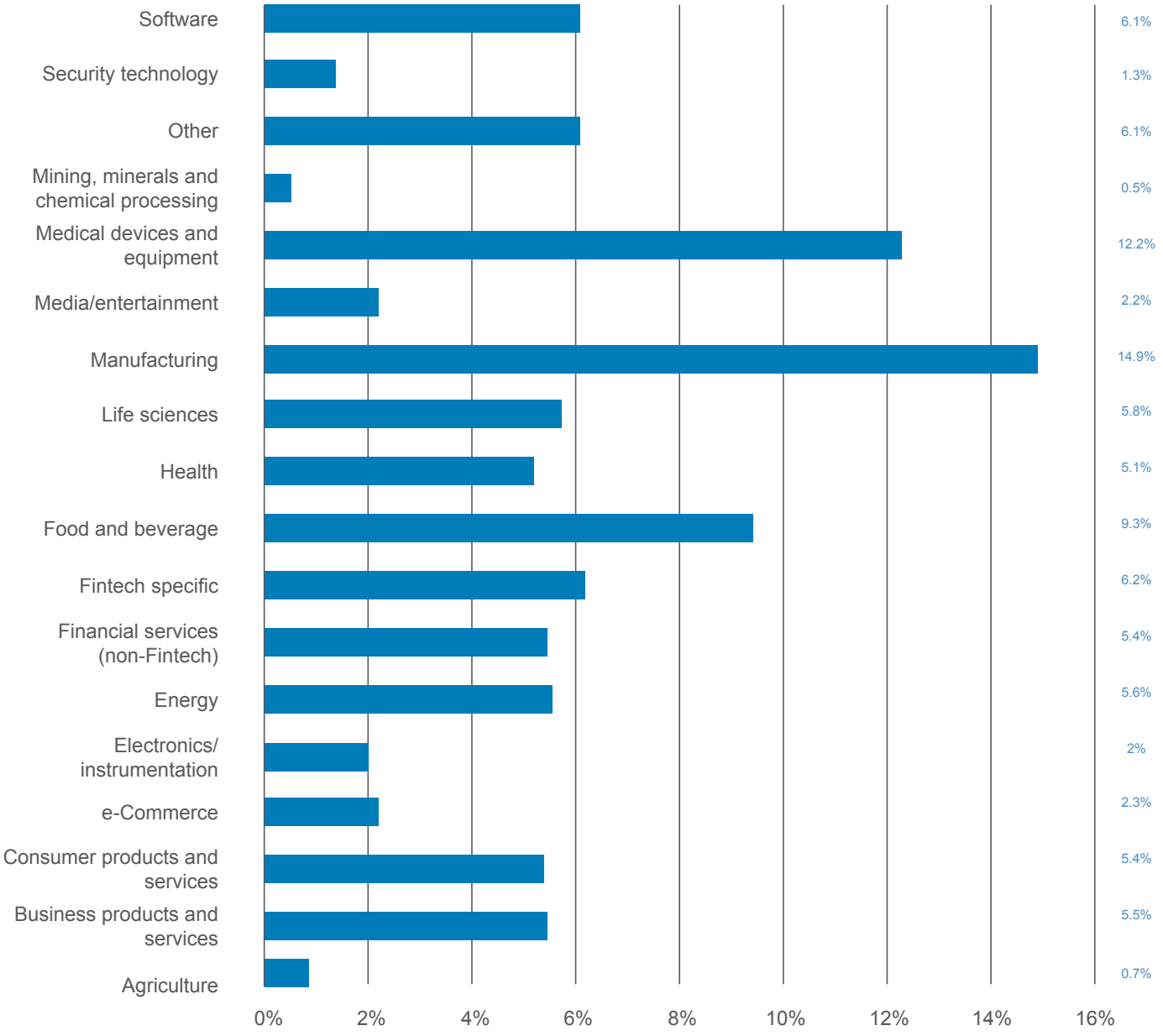


Figure 4.5: *Proportion of venture capital investments by sector*

Source: 2017 Venture Capital Survey (SAVCA)

18 SAVCA (2017) "Venture Capital Survey"

With effect from 1 July 2009, investors (any taxpayer) can claim income tax deductions in respect of the expenditure incurred in exchange for venture capital company shares. Section 12J was introduced to cater for deductions in respect of expenditure incurred in exchange for the issue of venture capital company shares. The venture capital company regime is subject to a 12-year sunset clause (ending on 30 June 2021). Data from the South African Revenue Service (SARS) informs that the uptake of individual investors into Section 12J venture capital companies at February 2017 totalled 892 investors. This shows that venture capital activities are open to a relatively large number of investors.

4.2 LINKAGES AND ENTREPRENEURSHIP

As innovation does not take place in isolation, appropriate linkages need to be established between different sectors to facilitate knowledge and technology transfer. The types of linkages that are the focus of this section are public-private partnerships (PPPs).

4.2.1 Public-private partnerships on innovation-related projects

A PPP is a useful risk-sharing and resource-pooling mechanism on projects that have a long-term benefit to one or more stakeholders from the public and private sectors. In this definition of a PPP, the three significant words are risk, resources and benefit.

Large infrastructure-type innovation projects involve some higher level of risk and uncertainty on issues such as capital availability, social acceptance, political support and policy certainty (Figure 4.6). Whereas the private-sector partner typically takes care of capital availability risk, especially during periods of a constrained public budget, the public-sector partner takes care of policy certainty and the regulatory burden.

<table>
<tr><th>RISK CATEGORIES</th><th>DEVELOPMENT PHASE</th><th>CONSTRUCTION PHASE</th><th>OPERATION PHASE</th><th>TERMINATION PHASE</th></tr>
<tr><td rowspan="8">Political and regulatory</td><td>Environmental review</td><td>Cancellation of permits</td><td>Change in tariff regulation</td><td>Contract duration</td></tr>
<tr><td rowspan="2">Rise in pre-construction costs (longer permitting process)</td><td rowspan="2">Contract renegotiation</td><td></td><td>Decommission</td></tr>
<tr><td></td><td>Asset transfer</td></tr>
<tr><td colspan="2"></td><td>Currency convertibility</td><td></td></tr>
<tr><td colspan="4">Change in taxation</td></tr>
<tr><td colspan="4">Social acceptance</td></tr>
<tr><td colspan="4">Change in regulatory or legal environment</td></tr>
<tr><td colspan="4">Enforceability of contracts, collateral and security</td></tr>
<tr><td rowspan="6">Macro economic and business</td><td>Pre-funding</td><td colspan="3">Default of counterparty</td></tr>
<tr><td colspan="2" rowspan="3">Financial availability</td><td>Refinancing risk</td><td></td></tr>
<tr><td>Liquidity</td><td></td></tr>
<tr><td>Volatility of demand/market risk</td><td></td></tr>
<tr><td colspan="4">Inflation</td></tr>
<tr><td colspan="4">Real interest rates</td></tr>
<tr><td colspan="4">Exchange rate fluctuation</td></tr>
<tr><td rowspan="6">Technical</td><td colspan="3">Governance and management of the project</td><td rowspan="5">Termination value different from expected</td></tr>
<tr><td colspan="3">Environmental</td></tr>
<tr><td>Project feasibility</td><td rowspan="2">Construction delays and cost over-runs</td><td rowspan="2">Qualitative deficit of the physical structure/ service</td></tr>
<tr><td>Archaeological</td></tr>
<tr><td colspan="3">Technology and obsolescence</td></tr>
<tr><td colspan="4">Force majeure</td></tr>
</table>

Figure 4.6: *Risks linked to infrastructure assets over the project lifecycle*

Source: Selected good practices for risk allocation and mitigation in infrastructure in Asia-Pacific Economic Cooperation (APEC) economies (OECD)

While the wealth of technical and industry knowledge brought in by the reputable industry partner is undisputed, there are typically different perspectives of the project benefit among the public-sector and private-sector partners. The public-sector partner's objectives in the PPP are aimed at improved service delivery, whereas the private-sector partner seeks a financial return.

National Treasury maintains a database of PPP projects. Table 4.3 shows the active South African innovation-related PPPs for energy, waste, water and IT infrastructure projects. There are seven active energy PPP projects in the energy sector, of which two are at the inception stage, three are at the feasibility study phase and three are at the procurement stage. The two energy PPPs that are at the inception stage are the Free State Provincial Government's waste-to-energy processing plant and the Midvaal Local Municipality's electricity services project. The energy projects at the feasibility study phase are the City of Cape Town's Alternative Service Delivery Mechanisms for Council's Composting Plants in Cape Town Project and Drakenstein Municipality's waste-to-energy project. In the IT sector, the PPP that is at the inception stage is the Western Cape Provincial Government's Broadband Initiative Project.

Table 4.3: *Active innovation-related PPPs*

	NUMBER OF PROJECTS	PROJECT STAGE
Energy	7	2 x inception; 2 x feasibility study; 3 x procurement
IT	1	1 x inception
Waste	3	1 x inception; 2 x feasibility study
Water	4	3 x feasibility study; 1 x procurement

Source: National Treasury

The active waste-sector PPP projects are the Ditsobotla Local Municipality's waste water treatment project (at the inception stage), Eden District Municipality's Mossel Bay and Oudtshoorn regional waste landfill project (at the feasibility study stage) and the eThekwini Municipality's reclamation and re-use of treated sewage effluent for potable water (at the feasibility study stage). Lastly, the four water-sector PPP projects are the Department of Water and Sanitation's Pongolapoort Dam development (at the feasibility study stage), Lephalale Municipality's bulk water and reticulation, and sanitation project (at the feasibility study stage), eThekwini Municipality's Kwa-Mashu waste water treatment project (at the feasibility study stage) and Sedibeng Municipality's waste water treatment project (at the procurement stage).

There are several other innovation-related PPP projects that are being conceptualised, such as the Sovereign Innovation Fund. This PPP is aimed at commercialising innovations from ideas from the public and private sectors. In the 2017/18 financial year, the DST was planning to develop its business case in consultation with other government departments, such as the dti, the Economic Development Department (EDD) and the DSBD. Various governments around the world have initiated such Fund of Funds in support of innovation commercialisation for start-ups and seed capital. A notable example is the UK Innovation Investment Fund (UKIIF), which supports the creation of viable investment funds that target high-growth technology-based businesses in the UK. It has invested through two underlying Funds of Funds – the UK Future Technology Fund and the Hermes Environmental Impact Fund.

4.3 INTELLECTUAL PROPERTY RIGHTS REGIME: RECENT DEVELOPMENTS

Intellectual property rights refer to rights conferred by law for creations of the mind, both artistic and commercial. Artistic creations are covered by copyright laws, which protect works such as books, films, music, paintings, photographs and software, and give the copyright holder exclusive rights to control the reproduction or adaptation of such works for a certain period of time. Commercial or industrial intellectual property (IP) includes inventions, designs, trademarks and service marks, plant breeders' rights (PBRs), commercial names and designations. Industrial IPRs are protected by patents, registered trademarks, registered industrial designs and integrated circuits, and geographical indications (appellations).

4.3.1 Patents

The complexity of patents in their modus operandi and the high stakes surrounding their ownership has made them the primary vehicle of attention and debate internationally. The theoretical objective of IPRs is to supplement market forces, which on their own do not lead to desirable levels of research and development or innovation. "Broadly speaking, in an environment lacking adequate IPRs, inventors will not invent (or they will invent less than what is optimal) as they

will receive few, if any, benefits from their creative work. To use an economic explanation, positive externalities are present, or arise, when property rights cannot be clearly assigned. Society benefits from inventions, but the benefits to the inventors may not be reflected in the prices charged for the goods and services provided by the invention; hence invention activity is suboptimal".[19]

The benefits of the patent system arise from its dual mission, that is, to encourage invention and the diffusion of technology. However, patents have a number of deficiencies. They can create monopolies, innovation can suffer from gridlock when too many people own pieces of one thing (one innovation), the system may suffer from "patent trolling" (attorneys blackmailing operational businesses by threatening them with litigation over dubious patents) or "patent thickets" (the foreclosure of a market by erecting a dense web of patents).

The issue of development is closely linked to patent protection and technology transfer. It is argued[20, 21] that developed countries have "kicked away the ladder" that they had climbed to reach the world's top economic position so that developing countries cannot use it and that recent IPR changes make development a lot harder.

It has been argued[22] that the non-examining patent regime[23] of the system is detrimental to innovation and economic development. The non-examining approach makes the system prone to granting patents on known or only trivially modified inventions that confer potential market power, granting patents that fall into excluded categories. It may restrict access, raise prices and enable the patent holder to use litigation as a competitive weapon without providing incentives for making genuine advances or disclosing such advances to the public.

Furthermore, patent applicants may use drafting language in such a way as to create a smokescreen that aims to hide the actual boundaries of the invention, and simultaneously increase the number of claims. Such approaches pollute the prior art and increase the overall uncertainty. Finally, the system creates an asymmetry, disadvantaging South African inventors who cannot afford to protect their inventions internationally, and exposes the local system to potential capture by foreign interests.

The NACI (2017)[24] report on indicators identifies that, during recent years, up to two thirds of the patents granted for South Africa were to foreign interests. This is in contrast to international experience where the majority of patents are granted to local interests. In July 2016, the dti released a document titled "Intellectual Property Consultative Framework". Its stated purpose was to put forward the dti's perspective in a consultative instrument to facilitate what was intended to be continuous engagement with governmental partners and society at large. The framework refers to substantive search and examination (SSE) that is required prior to the granting of patents.

In 2015, in the context of the above-mentioned issues, the Companies and Intellectual Property Commission (CIPC) recruited the first 20 examiners with different technical backgrounds (including biotechnology/molecular biology, biochemistry, chemistry, engineering, mining, physics and information technology). Out of the 20 future examiners, 11 have PhD degrees, six have master's and two have honours degrees. The patent examiners are currently undergoing a two-year extensive training programme before they can start with work on priority art searches and the substantive examination of patents. The qualifications of the examiners indicate that emphasis will be placed on life sciences.

The move to an examining system is expected to have disruptive effects. The cost should be expected to increase and the number of granted patents should be expected to decrease substantially. It should be emphasised that the current fees are among the cheapest in the world. The introduction of an examination system will weed out non-qualifying patents and the increase in fees will further eliminate applications for patents that are not expected to cover costs.

An indication of the number of South African patents is given by the grants of foreign patent-granting authorities. Figure 4.7 shows the number of patents awarded to South African inventors by the United States Patent and Trademark Office (USPTO) during the period 2000–2015.

19 Pouris, A. (2011) "Patents and economic development in South Africa: managing intellectual property rights", *South African Journal of Science* 107(11–12)
20 Chang, H.J. (2008) *Bad Samaritans: the myth of free trade and the secret history of capitalism*, Bloomsbury Press, New York, NY
21 List, F. (1841) *The national system of political economy*, Longmans, Green and Company, London
22 Pouris, A. (2011) "Patents and economic development in South Africa: managing intellectual property rights", *South African Journal of Science* 107(11–12)
23 The Companies and Intellectual Property Commission (CIPC) in South Africa does not investigate the novelty or inventive merit of the invention – only the documentation, and not the substance of the product or process, is verified
24 National Advisory Council on Innovation (NACI) (2017) "2016 South African science technology and innovation indicators", NACI, Pretoria

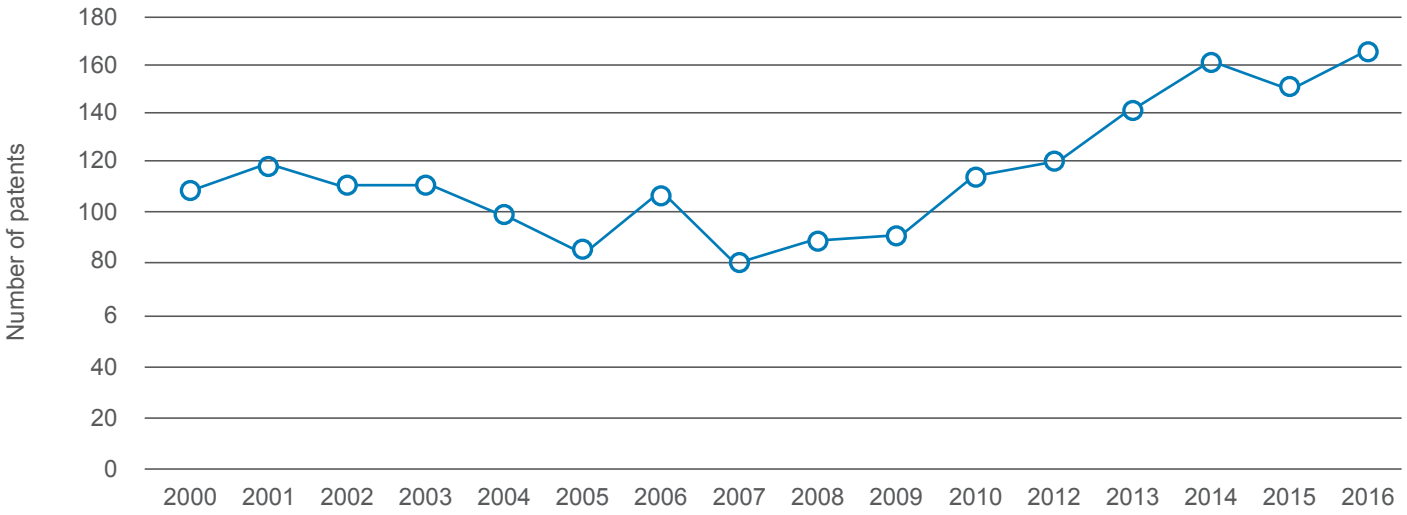


Figure 4.7: *Patents granted to South African inventors*

Source: USPTO

The most recent years exhibit an increase in the number of patents awarded to South Africans. It should be noted that the granting of 160 patents to South African inventors is an all-time high. South Africa was ranked 32nd during 2015 according to the number of patents granted by USPTO. However, South Africa, in general, gets very few patents from USPTO. Japan is granted more than 50 000 patents a year, and companies like IBM are granted more than 3 000 patents a year.

Table 4.4 identifies the most prolific South African organisations that were awarded utility patents by USPTO between 2011 and 2015. Patent origin is determined by the residence of the first-named inventor. Individually owned patents were the majority. Sasol Technology was at the top of the list with 48 patents during the period.

Table 4.4: *Patent grants of the most prolific assignees in South Africa*

FIRST-NAME ASSIGNEE	PATENT GRANTS (2011–2015)	PATENT GRANTS (2015)
Individually owned	134	16
Sasol Technology	48	10
Amazon Technologies	29	12
CSIR	23	11
University of the Witwatersrand	22	8
Spinalmotion	20	1
University of Cape Town	15	1
Cork Group Trading	14	4
Element Six Abrasives	14	6
Joy MM Delaware	12	3

Source: USPTO

4.3.2 Plant breeders' rights

The most commonly used IP protection for plant varieties is plant breeders' rights. This alternate IP protection grants the breeder of a new plant variety the exclusive rights to benefit from this innovation. According to the International Union for the Protection of New Varieties of Plants (UPOV), its system of plant variety protection came into being with the adoption of the International Convention for the Protection of New Varieties of Plants by a Diplomatic Conference in Paris on 2 December 1961. This was the point at which there was recognition of the IPRs of plant breeders in their varieties on an international basis.

In South Africa, the Plant Breeders' Rights Act (Act No. 15 of 1976) defines variety as any plant grouping within a single botanical taxon of the lowest known classification, which grouping, irrespective of whether or not the conditions for the grant of a PBR are fully met, can be:

(a) defined by the expression of the characteristics resulting from a given genotype or combination of genotypes;
(b) distinguished from any other plant grouping by the expression of at least one of the said characteristics; and
(c) considered as a unit with regard to its suitability for being propagated unchanged.

Plants are identified, classified and described according to the following hierarchy (taxonomic groups) that is arranged from the high to low: kingdom, division, class, order, family, genus and species. One example is the rooibos, a well-known indigenous shrub of Southern Africa, which has the following classification:

Kingdom: Plantae
Division: Magnoliophyta (flowering plants)
Class: Magnoliopsida
Order: Fabales
Family: Fabaceae
Genus: *Aspalathus*
Species: *Aspalathus linearis* (rooibos)

From a database of PBRs that are still in force, as registered by the Department of Agriculture, Forestry and Fisheries (DAFF), 206 plant species and 2 933 subspecies are attributed to approximately 576 organisations or partners from various countries. The ARC has registered 369 subspecies, which represent 13% of the plant varieties registered on DAFF's *South African Plant Variety Journal*. Table 4.5 shows that, overall, there is an increase in the annual PBRs granted in South Africa. The PBRs granted to the ARC shows a cyclic pattern, with the highest points being awarded during 2009 and 2012, with 33 and 39 PBRs being granted respectively.

Table 4.5: *Annual statistics of the PBRs granted in South Africa*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total PBRs granted	161	204	124	209	239	243	238	234	228	250
ARC PBRs granted	5	20	33	14	9	39	23	12	7	3

Source: South African Plant Variety Journal (DAFF)

The cyclic pattern of the ARC's PBRs granted is illustrated in Figure 4.8. In 2009, the ARC had a share of 26.6% of the PBRs granted in the country. This share was only 1.2% in 2016. According to the ARC's annual report of 2016/17, examples of its breeding projects are the breeding of potatoes tolerant to Alternario (fungus) brown spot, new avocado selection to produce a highly sought fruit with a higher flesh percentage, and a small seed, guava breeding programme.

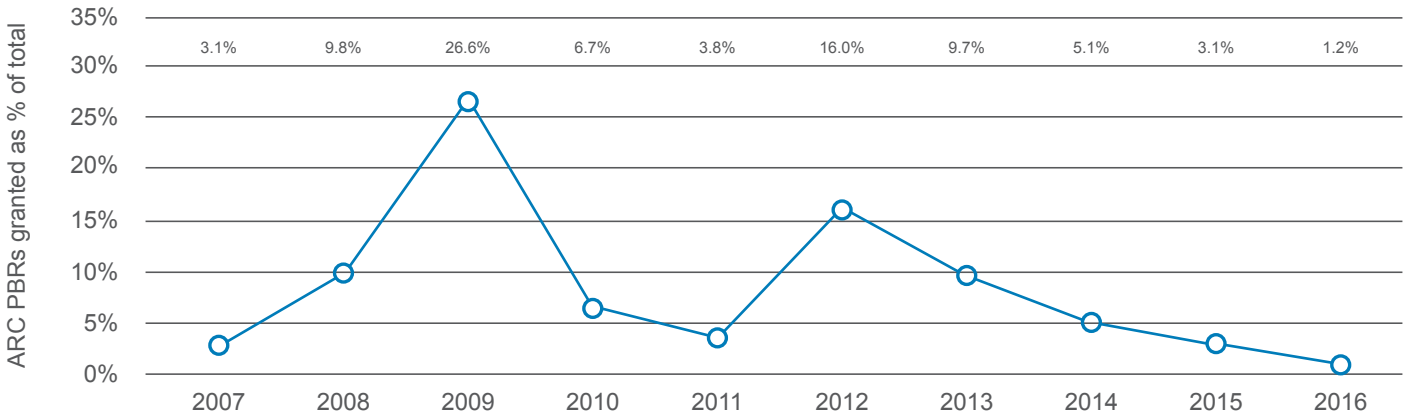


Figure 4.8: *ARC's PBRs granted as a percentage of the total*

Source: South African Plant Variety Journal (DAFF)

Table 4.6 shows the distribution of PBRs granted to the ARC's institutes or divisions. Most of the plant variety discoveries are made in the Deciduous Fruit, Vine and Wine Division, although there are pockets of excellence at the ARC's other campuses, such as the Vegetable and Ornamental Plants Institute (VOPI) and Small Grain Institute (SGI).

Table 4.6: *PBRs granted to the ARC*

ARC CAMPUSES	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Vegetable and Ornamental Plants Institute	2	4	2	7	1	0	7	0	0	3
Grain Crops Institute	0	2	0	1	2	4	1	0	3	0
Deciduous Fruit, Vine and Wine Division	3	12	27	3	4	23	8	8	3	0
Institute of Tropical and Subtropical Crops	0	1	2	0	0	2	2	1	1	0
Institute of Industrial Crops	0	0	0	0	2	0	1	1	0	0
Small Grain Institute	0	0	2	1	0	7	2	2	0	0
Animal Production Institute	0	0	0	2	0	0	1	0	0	0
Other	0	1	0	0	0	2	1	0	0	0
Total	**5**	**20**	**33**	**14**	**9**	**39**	**23**	**12**	**7**	**3**

Source: South African Plant Variety Journal (DAFF)

Table 4.7 shows that it is only the University of Stellenbosch that is very active in the higher education sector for plant breeding innovations. More effort is needed to incentivise other universities to contribute to increasing and conserving South Africa's plant diversity.

Table 4.7: *PBRs granted to South African universities*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
University of Stellenbosch	0	0	1	1	1	0	0	0	4	0

Source: South African Plant Variety Journal (DAFF)

5. INNOVATION OUTPUTS

The process of innovation is not complete if it does not include the desired economic and social impacts. Various frameworks that relate innovation to the performance of the economy have been developed. The most famous is the Schumpeterian Theory of Innovation. Indeed, there are several accounts of the strong links between the level of innovation and the economic performance of various advanced countries. A variety of innovations have also been useful in tackling the societal challenges that are related to issues such as food security, safety and peace, mobility, health, energy, environmental protection and shelter. This section shows the state of STI in addressing economic and societal needs.

5.1 INNOVATION FOR ECONOMIC IMPACT

The technology balance of payments (TBP) comprises trade in embodied and disembodied technologies. The performance of embodied technologies is best represented by trade performance in terms of exports and imports. As the disembodied technologies represent the stock of IP or know-how, their trading activities are best represented by the charges for the use of IP, both payments and receipts. This section focuses on the embodied technologies as part of the TBP, as well as value-added components in different economic sectors.

5.1.1 Technology balance of payments

The analysis of merchandise exports by the technology intensiveness of manufactured products (Table 5.1) shows that the country is relatively competitive in the medium-technology sectors, such as the automotive industry, process technology (chemicals, structural material, tubes and pipes, trailers and semi-trailers, and railway vehicles and associated equipment) and the engineering industries (plant, engines and motors, agricultural machinery, civil engineering machinery, pulp and paper machinery, food processing machines, liquids pumps, transmission shafts, radio broadcast receivers, ships and boats, and arms and ammunition).

Other areas of strength in terms of exports are non-agricultural resource-based manufacturers, as well as primary products. High-technology (electronic and electrical, pharmaceuticals, aeroplane, and scientific and precision instruments) and low-technology sectors have relatively low shares of South African merchandise exports (4.0% and 7.1% respectively in 2016). Between 2007 and 2016, there has been a dramatic growth in the share of exports made up of unclassified products (electric current, exposed and developed cinematographic films, printed matter, work of art, coins and non-monetary gold). The textiles, garments and footwear industry has also shown good growth in exports, although this is from a low baseline of export share (0.9% in 2007).

Table 5.1: *Proportion of South African merchandise exports by technological intensity*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
High technology	**3.8**	**3.4**	**3.6**	**3.4**	**3.0**	**3.4**	**3.3**	**3.9**	**4.0**	**4.0**
Electronic and electrical	2.1	1.9	2.2	2.0	1.8	2.0	2.0	2.4	2.3	2.2
Other	1.6	1.5	1.4	1.4	1.2	1.3	1.3	1.5	1.7	1.9
Medium technology	**28.6**	**32.1**	**28.1**	**29.2**	**25.0**	**26.6**	**26.3**	**28.7**	**29.9**	**30.5**
Automotive	7.7	9.8	9.1	9.0	7.6	8.5	8.2	9.4	11.1	11.9
Process	10.8	12.9	10.8	11.4	9.3	9.6	9.8	10.9	10.4	10.4
Engineering	10.1	9.4	8.2	8.8	8.1	8.5	8.3	8.5	8.4	8.2
Low technology	**9.3**	**7.3**	**7.7**	**8.8**	**6.8**	**7.2**	**6.8**	**7.3**	**7.1**	**7.1**
Textiles, garments and footwear	0.9	0.7	0.8	1.3	1.2	1.3	1.4	1.5	1.6	1.5
Other products	8.4	6.5	6.9	7.4	5.6	5.9	5.4	5.8	5.6	5.6

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
Resource-based	**23.3**	**26.3**	**28.3**	**29.3**	**28.7**	**29.1**	**30.7**	**30.1**	**27.5**	**26.4**
Agro	5.5	5.3	7.1	7.1	6.0	6.2	6.5	6.9	7.2	7.1
Other	17.8	21.0	21.1	22.2	22.7	22.9	24.2	23.3	20.3	19.4
Primary products	**33.9**	**30.1**	**31.6**	**28.0**	**25.9**	**23.7**	**24.8**	**23.4**	**27.0**	**25.0**
Unclassified products	**1.1**	**0.8**	**0.8**	**1.3**	**10.6**	**10.0**	**8.2**	**6.6**	**4.5**	**6.9**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: United Nations Conference on Trade and Development (UNCTAD)

On the import front, as with exports, the shares of high- and low-technology imports is also relatively low, relative to medium-technology imports, although higher relatively speaking than their respective low shares of the country's exports (Table 5.2).

Table 5.2: *Proportion of South African merchandise imports by technology intensity*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
High technology	**15.7**	**15.9**	**17.9**	**17.8**	**16.5**	**15.3**	**16.1**	**15.7**	**17.2**	**17.8**
Electronic and electrical	10.9	10.7	11.9	11.8	10.5	9.9	11.5	11.2	12.4	12.0
Other	4.8	5.2	6.0	6.0	6.0	5.5	4.6	4.5	4.8	5.8
Medium technology	**32.4**	**29.9**	**28.8**	**29.1**	**29.6**	**29.6**	**29.7**	**28.3**	**29.3**	**29.5**
Automotive	9.6	6.9	6.7	8.2	8.4	8.4	8.3	7.7	7.9	7.3
Process	6.8	6.8	6.9	7.1	7.0	7.0	7.2	7.5	8.3	8.0
Engineering	16.1	16.2	15.2	13.8	14.1	14.2	14.2	13.1	13.1	14.1
Low technology	**9.6**	**9.1**	**10.5**	**10.7**	**10.5**	**10.0**	**10.4**	**10.1**	**11.1**	**11.7**
Textile, garment and footware	3.4	3.0	4.0	4.3	4.2	4.0	4.2	4.2	4.7	5.1
Other products	6.2	6.1	6.5	6.4	6.3	6.0	6.2	5.9	6.3	6.6
Resource-based	**15.8**	**15.2**	**14.9**	**16.2**	**17.2**	**17.1**	**17.4**	**16.5**	**16.1**	**15.8**
Agro	5.0	4.7	5.6	5.8	5.6	5.9	5.7	5.5	5.2	6.3
Other	10.8	10.4	9.3	10.5	11.6	11.2	11.7	11.0	10.8	9.6
Primary products	**18.6**	**22.7**	**21.6**	**19.0**	**19.8**	**21.1**	**19.8**	**22.2**	**17.1**	**16.5**
Unclassified products	**7.8**	**7.2**	**6.3**	**7.1**	**6.5**	**6.7**	**6.6**	**7.2**	**9.3**	**8.7**
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: UNCTAD

The shares of medium-technology exports and imports as a percentage of total exports and imports are nearly the same at around 30%, although the engineering industries account for a greater share of imports than exports.

Table 5.3 confirms the overall balance that exists between exports and imports of medium-technology products. The automotive industry contributes positively to the balance of payments, whereas the engineering industries are contributing adversely to the trade balance. The high-technology sector's exports represented only 22.6% of this sector's imports in 2016, which is slightly up from 19.2% in 2007. A contribution to this high trade deficit is caused by electronic and electrical products (18.1% in 2016). Overall, there was an encouragingly solid improvement in South Africa's merchandise trade balance in 2016 as the exports, as a percentage of imports, reached 99.2%. This is the best such ratio since 2011. Exports increased, while imports fell in 2016.

Table 5.3: *Merchandise exports as a percentage of imports*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
High technology	**19.2**	**18.2**	**16.9**	**19.1**	**19.2**	**20.8**	**18.7**	**22.5**	**20.5**	**22.6**
Electronic and electrical	15.5	14.9	15.6	17.0	17.6	19.5	15.9	19.5	16.5	18.1
Other	27.5	25.0	19.5	23.1	21.9	23.1	25.7	29.7	30.7	31.9
Medium technology	**70.8**	**90.7**	**82.3**	**100.1**	**89.1**	**85.3**	**81.3**	**92.0**	**89.2**	**102.7**
Automotive	64.4	120.1	114.3	109.8	95.8	96.7	90.6	110.1	123.8	161.2
Process	128.2	160.2	131.3	160.2	138.8	129.1	125.4	131.9	109.1	128.7
Engineering	50.4	48.9	45.8	63.5	60.2	56.9	53.6	58.5	55.9	57.3
Low technology	**77.9**	**67.5**	**62.0**	**81.5**	**68.2**	**68.1**	**59.6**	**65.2**	**56.3**	**59.9**
Textile, garment and footware	22.4	20.7	16.5	30.9	29.9	29.8	30.2	32.1	28.9	29.0
Other products	108.1	90.7	89.7	115.9	94.0	93.7	79.4	88.8	76.8	83.7
Resource-based	**118.1**	**146.3**	**160.5**	**179.9**	**175.2**	**161.3**	**161.9**	**165.9**	**149.8**	**165.4**
Agro	88.0	94.1	108.0	123.2	112.3	100.0	104.3	114.1	120.4	111.8
Other	132.0	169.9	192.1	211.1	205.6	193.5	190.0	191.7	164.0	200.5
Primary products	**146.2**	**112.3**	**123.3**	**146.5**	**137.5**	**106.4**	**114.9**	**95.7**	**138.1**	**150.5**
Unclassified products	**11.3**	**8.8**	**10.5**	**17.8**	**171.9**	**141.8**	**115.7**	**83.0**	**42.4**	**78.8**
Total	**80.2**	**84.4**	**84.5**	**99.6**	**105.1**	**94.9**	**91.9**	**90.7**	**87.5**	**99.2**

Source: UNCTAD

Table 5.4 provides an in-depth analysis of the contribution of high-technology industries to South Africa's economic competitiveness in terms of exports, as a percentage of imports. The trade deficit in electronic and electrical products is caused mainly by office machinery and automatic data-processing machines (14.8% in 2016), telecommunications and sound-recording apparatus (15.4%), and parts and components for electrical and electronic goods (17.7%) industries.

The trade deficit is also high in respect of precision equipment, as well as medicinal and pharmaceutical products. However, the trade deficit for medicinal and pharmaceutical products is decreasing according to CUSTOS Research, as "several multinational drug-makers choose to manufacture medicines locally in South Africa, designating the market as their production hub for sub-Saharan Africa".[25]

South Africa's local pharmaceutical industry is more developed in terms of local drug-makers' manufacturing capabilities compared with other sub-Saharan African drug-makers. They have become increasingly competitive in terms of medicine production. Pharmaceutical imports are predicted to remain high, as the country is still heavily reliant on imported products, particularly with regard to the more advanced pharmaceuticals.

25 http://www.pharmaceuticalsinsight.com/industry-trend-analysis-pharmaceutical-imports-will-continue-dominate-nov-2017

From 2007 to 2008, there was a notable sharp decline in exports, as a percentage of imports, in respect of power-generating machinery and equipment products. This is probably due to a massive R340 billion Eskom Build Programme, which commenced in 2005, with the objective of adding an additional 17 GW of electricity-generating capacity to the national grid by 2018/19.

Table 5.4: *High-technology exports as a percentage of imports*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
Electronic and electrical	**15.5**	**14.9**	**15.6**	**17.0**	**17.6**	**19.5**	**15.9**	**19.5**	**16.5**	**18.1**
Power-generating machinery and equipment	51.8	39.3	34.4	35.2	31.1	37.0	37.4	41.0	32.7	39.0
Office machines and automatic data-processing machines	8.3	8.9	8.8	11.4	11.2	13.5	11.8	13.0	11.9	14.8
Parts and components for electrical and electronic goods	13.5	15.1	14.9	16.7	17.1	18.4	16.2	20.4	18.3	17.7
Telecommunication and sound-recording apparatus	12.8	10.8	11.1	10.6	11.9	16.1	16.6	22.9	15.1	15.4
Electrical machinery, apparatus and appliances not elsewhere specified.	27.2	29.0	28.0	38.1	40.2	37.8	29.5	34.0	34.1	34.0
Other	**27.5**	**25.0**	**19.5**	**23.1**	**21.9**	**23.1**	**25.7**	**29.7**	**30.7**	**31.9**
Medicinal and pharmaceutical products	10.1	11.8	11.5	18.9	21.3	18.5	19.2	20.5	18.9	22.6
Other transport equipment	43.8	35.4	29.7	39.3	35.8	44.0	69.7	54.9	44.2	45.6
Professional and scientific instruments	19.2	22.8	23.3	28.5	28.8	26.9	26.9	34.1	33.4	34.8
Photo apparatus, optical goods, watches and clocks	15.0	16.2	15.2	20.4	18.4	17.0	16.0	17.5	19.3	18.3
Total	**19.2**	**18.2**	**16.9**	**19.1**	**19.2**	**20.8**	**18.7**	**22.5**	**20.5**	**22.6**

Source: UNCTAD

Another notable improvement in reducing the trade deficit is in respect of professional and scientific instruments. This category includes optical instruments and apparatuses, medical instruments and appliances, meters and counters, and measuring, analysing and controlling apparatuses.

An analysis of South Africa's merchandise trade performance reveals existing and emerging areas of strength. It is important for the country to identify such strengths and technology demand conditions of other regions. In order to appraise the trade performance of each region, as shown in Table 5.5, it is important to gauge this in relation to the population share of each region during 2016: Africa (16.4%), Europe (9.9%), America (13.5%), Asia (59.7%) and Oceania (0.5%). Any values above these percentages of the world population indicate a relatively high value and conversely for values below these benchmarks.

Table 5.5: *Share of merchandise trade by region, 2007–2016*

	EXPORTS					IMPORTS				
	AFRICA	EUROPE	AMERICA	ASIA	OCEANIA	AFRICA	EUROPE	AMERICA	ASIA	OCEANIA
	PERCENTAGE									
High technology	**0.3**	**34.4**	**13.4**	**51.6**	**0.3**	**1.8**	**32.5**	**21.6**	**42.7**	**1.3**
Electronic and electrical	0.2	22.6	12.6	64.4	0.2	1.6	26.8	22.0	48.3	1.2
Other	0.3	61.3	15.5	22.3	0.6	2.3	46.1	20.6	29.4	1.6
Medium technology	**1.0**	**46.6**	**17.2**	**34.8**	**0.3**	**3.7**	**40.1**	**23.9**	**30.5**	**1.9**
Automotive	0.8	50.2	20.9	27.8	0.2	3.5	44.9	30.8	18.4	2.5
Process	1.5	45.6	16.6	35.9	0.4	4.0	39.6	18.2	36.8	1.4
Engineering	0.8	45.3	15.5	38.0	0.4	3.7	37.7	23.3	33.5	1.9
Low technology	**1.2**	**38.6**	**9.5**	**50.4**	**0.3**	**3.1**	**43.9**	**24.0**	**27.3**	**1.7**
Textile, garment and footware	1.8	29.6	6.3	62.0	0.2	2.7	43.9	24.7	27.0	1.6
Other products	0.8	44.2	11.5	43.1	0.4	3.3	43.8	23.6	27.4	1.8
Resource-based	**0.9**	**44.5**	**19.4**	**32.0**	**3.2**	**4.1**	**38.4**	**18.7**	**37.2**	**1.6**
Agro	1.9	51.9	19.4	24.9	1.8	4.7	46.0	19.5	27.9	1.9
Other	0.3	40.4	19.4	35.9	4.0	3.8	34.2	18.3	42.2	1.5
Primary products	**11.0**	**28.2**	**20.6**	**36.5**	**3.7**	**2.9**	**36.3**	**18.6**	**41.3**	**1.0**
Unclassified products	**2.2**	**47.2**	**25.3**	**22.5**	**2.8**	**1.9**	**44.7**	**18.1**	**33.6**	**1.6**
Total	**2.7**	**39.6**	**16.9**	**39.3**	**1.5**	**3.1**	**38.3**	**21.4**	**35.7**	**1.5**

Source: UNCTAD

It follows that Africa's exports are low in comparison to its 16.4% world population share benchmark. This is the same for its share of imports in all the product groups. Exports from Africa during 2007–2016 were relatively high in respect of primary products (11.0% world share), followed a long way behind by its share of exports in unclassified products (2.2%), low-technology products (1.2%), medium-technology products (1.0%) and resource-based manufactures (0.9%). It is not clear how the 2024 Science, Technology and Innovation Strategy for Africa (STISA) will accelerate Africa's transition to an innovation-led, knowledge-based economy, as there is a lack of emphasis on high and medium technology in this strategy.

Europe's share of exports is well above its 9.9% world population share benchmark in respect of all product groups. The same applies to the imports. In addition to unclassified products, Europe's exports are relatively high for medium-technology products (46.6% world share), followed by resource-based manufacturers. This export structure at the higher level resembles that of South Africa. America is also performing below its 13.5% world population share benchmark in some of the product groups, in particular in respect of low- and high-technology export products. As a result, it is in respect of these two product groups that America is proportionately sourcing the biggest share of its imports.

Even though Asia's share of high-technology exports is relatively large (51.6% during 2007–2016), this is below its world population share benchmark of 59.7%. On the positive side, Asia's world share of exports of high-, medium- and low-technology products is larger than that of its imports of such products.

Oceania's strength is relatively high in primary products and resource-based products, but its share of high-, medium- and low-technology export products is well below its 0.5% world population share benchmark.

The prioritisation of South African technologies should take these regional strengths and weaknesses into account in order to create market opportunities. A more detailed regional analysis for high-technology trade is shown in Table 5.6.

Table 5.6: *Regional share of high-technology merchandise trade, 2007–2016*

	EXPORTS					IMPORTS				
	AFRICA	EUROPE	AMERICA	ASIA	OCEANIA	AFRICA	EUROPE	AMERICA	ASIA	OCEANIA
	PERCENTAGE									
Electronic and electrical	**0.2**	**22.6**	**12.6**	**64.4**	**0.2**	**1.6**	**26.8**	**22.0**	**48.3**	**1.2**
Power-generating machinery and equipment	0.4	53.3	19.3	26.7	0.3	3.1	39.9	26.6	29.1	1.3
Office machines and automatic data-processing machines	0.1	22.3	12.4	65.0	0.2	1.4	34.6	27.3	35.0	1.8
Parts and components for electrical and electronic goods	0.3	19.6	11.4	68.6	0.2	1.4	22.3	18.2	57.2	0.8
Telecommunication and sound-recording apparatus	0.3	22.1	13.5	64.0	0.2	2.2	30.3	28.4	37.4	1.6
Electrical machinery, apparatus and appliances not elsewhere specified	0.6	25.8	12.2	61.3	0.2	1.6	24.5	16.6	56.4	0.8
Other	**0.3**	**61.3**	**15.5**	**22.3**	**0.6**	**2.3**	**46.1**	**20.6**	**29.4**	**1.6**
Medicinal and pharmaceutical products	0.2	77.5	12.2	9.4	0.7	2.6	58.6	21.6	15.2	2.0
Other transport equipment	1.1	46.0	15.4	37.0	0.5	4.3	42.8	19.2	32.0	1.6
Professional and scientific instruments	0.3	36.9	20.4	41.8	0.6	1.8	31.6	21.0	44.0	1.6
Photo apparatus, optical goods, watches and clocks	0.1	41.8	8.4	49.4	0.3	1.0	32.9	15.9	48.7	1.4
Total	**0.3**	**34.4**	**13.4**	**51.6**	**0.3**	**1.8**	**32.5**	**21.6**	**42.7**	**1.3**

Source: UNCTAD

As shown, Africa's world share of trade in electrical machinery, apparatus and appliances is relatively large (0.6% during 2007–2016) although this is just a fraction of its world population share benchmark of 16%. High-technology imports into Africa mainly address the areas of mobility (transport equipment), energy (power-generating machinery and equipment), health (medicinal and pharmaceutical products) and communication (telecommunication and sound-recording apparatus.

Europe is the largest market for medicinal and pharmaceutical products, an area in which South Africa is increasing its strength. Oceania also has a relatively large appetite for these products, even though it is a relatively small market.

Asia's high-technology imports are relatively high in the parts and components for electrical and electronic goods, as well as electrical machinery, apparatus and appliances. America has a relatively large market for telecommunication and sound-recording apparatus, as well as office machinery and automatic data-processing machines.

It is clear that Africa (South Africa included) is trailing behind other regions with regard to trade in merchandise goods. The STI sectors of Africa need to respond to industrial policy strategies in order to capture the world markets through improved competitiveness.

5.1.2 Gross value added

The structure of the South African economy is shown in Table 5.7. It is clear that not much has changed over the past decade in terms of the contribution of the primary, secondary and tertiary sectors to the overall economy.

This re-emphasises the need for the STI sector to enable increased economic competitiveness by creating capabilities in areas such as pharmaceuticals, electronics and other high-technology industries. South Africa is a service-based economy, as illustrated by the large share of the tertiary industry within overall GDP (55.7% in 2016). This needs to be reversed in favour of export-oriented sectors, such as the manufacturing.

Table 5.7: *Proportion of value added by kind of economic activity*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	PERCENTAGE									
Primary sector	**9.4**	**10.3**	**9.7**	**9.7**	**9.9**	**9.4**	**9.3**	**8.8**	**8.3**	**8.4**
Agriculture, forestry and fishing	2.5	2.6	2.5	2.2	2.1	2.0	1.9	2.0	1.9	2.0
Mining and quarrying	7.0	7.7	7.2	7.6	7.8	7.4	7.4	6.8	6.4	6.4
Secondary sector	**17.7**	**18.4**	**17.7**	**17.1**	**16.6**	**16.7**	**16.8**	**17.2**	**17.3**	**17.1**
Manufacturing	13.4	13.3	12.3	11.8	10.9	10.6	10.5	10.9	10.9	10.8
Electricity, gas and water	1.5	1.5	1.9	2.2	2.6	2.9	3.0	3.0	3.1	3.0
Construction	2.9	3.6	3.5	3.1	3.1	3.2	3.3	3.3	3.4	3.2
Tertiary sector	**56.0**	**54.4**	**54.8**	**55.0**	**55.2**	**55.5**	**55.5**	**55.3**	**55.7**	**55.7**
Wholesale and retail trade, catering and accommodation	11.4	11.6	11.5	12.2	12.1	12.2	12.1	12.0	12.2	12.3
Transport, storage and communication	9.3	8.6	8.1	7.5	7.7	8.0	8.4	8.4	8.3	8.1
Finance, insurance, real estate and business										
services	18.5	17.4	17.4	17.2	17.0	16.9	16.5	16.4	16.5	16.4
Community, social and personal services	16.8	16.9	17.8	18.1	18.4	18.4	18.4	18.6	18.7	18.9
General government services	**11.7**	**12.0**	**12.9**	**13.3**	**13.4**	**13.5**	**13.7**	**14.0**	**14.0**	**14.2**
Other	**5.1**	**4.8**	**4.9**	**4.9**	**4.9**	**4.9**	**4.8**	**4.7**	**4.7**	**4.7**

Source: Online Statistical Query (South African Reserve Bank (SARB))

5.2 INNOVATION FOR INCLUSIVENESS AND SOCIAL IMPACT

The promotion of inclusivity in South Africa tackles the three major societal challenges of unemployment, inequality and poverty. Many policy analysts and think tanks around the world are constantly in search of indicators that best represent the contribution of STI to inclusiveness and social impact. Such quality-of-life/wellbeing indicators are not straightforward, as many non-STI factors contribute to wellbeing. In this section, employment and health are used as indicators. Most of the other hierarches of human needs, as defined by Maslow's theory, are reflected in the quality-of-life indices.

5.2.1 Employment in various sectors

Table 5.8 shows the relative change in employment in various non-agricultural sectors. Since 2010, approximately 8% of jobs have been lost in the mining sector. A large loss of jobs in this sector took place in 2016 specifically. The manufacturing sector has also suffered some job losses since 2010. Although the number of jobs in the construction sector is still relatively high in comparison to 2010, this sector is increasingly shedding jobs in the absence of infrastructural spending in civil engineering and building.

The financial and trade sectors are experiencing growth in number of jobs. As elaborated in the skills supply and demand in South Africa report of the HSRC, "a high proportion of science and engineering graduates from both the higher and technical vocational education sectors prefer to work in the financial services sector, as opposed to the manufacturing sector".[26]

Table 5.8: *Employment index by sector in the private sector*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	(2010 AS BASE YEAR)									
Construction	112.5	113.3	105	100	104.2	107	106.2	104.2	101	101.2
Financial institutions	102.6	106.6	101.9	100	102.8	104	104.9	104.1	105.4	106.2
Manufacturing	112.4	110.7	103.5	100	98.8	98.5	98.4	96.7	96.4	95.2
Mining	99.8	104.1	98.5	100	103.4	104.7	101.7	98.7	95.9	91.7
Trade	104.1	104	100.3	100	101.4	103.2	103.9	103.8	105.3	106.6
Total	**104.5**	**105.9**	**101.3**	**100**	**101.8**	**103.1**	**103.2**	**102.3**	**102.5**	**102.7**

Source: Online Statistical Query (SARB)

The public sector (both general government and business enterprises) added a significant number of jobs, although the trend is now reversing (Table 5.9). The rating agencies raised some concerns regarding a large public sector wage burden. Subsequent to that, government has frozen new job creation and has tried to restrain the public service wage bill.

Table 5.9: *Employment index in the public sector*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	(2010 AS BASE YEAR)									
General government	90.1	94.7	97.7	100	105	106.6	108.6	113.6	111.4	113.6
Business enterprises	104.4	103.9	103.6	100	101.1	109.6	122	124.6	123.7	113.5
Total	**90.9**	**95.2**	**98**	**100**	**104.8**	**106.7**	**109.3**	**114.1**	**112**	**113.6**

Source: Online Statistical Query (SARB)

5.2.2 Health indicators

A healthy life is the single-most important basic need for human survival, hence it being a key component of wellbeing and quality of life. Physiological needs are at the foundation of Maslow's hierarchy of needs. Table 5.10 shows that the survival rate for South Africans is increasing, as reflected by a sharply rising life expectancy at birth over the past decade (64 years in 2017, as opposed to 54.7 years in 2007).

Table 5.10: *Life expectancy at birth*

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Males	53.3	54.3	55	56.4	57.6	58.5	59.2	59.7	60	60.6	61.2
Females	56.1	57.9	58.7	60.6	62.7	63.6	64.6	65.1	65.5	66.1	66.7
Total	**54.7**	**56.1**	**56.9**	**58.5**	**60.2**	**61.1**	**61.9**	**62.5**	**62.8**	**63.4**	**64**

Source: 2017 Mid-year Population Estimates (Statistics South Africa)

26 Reddy, V., Bhorat, H., Powell, M., Visser, M. and Arends, A. (2016) "Skills supply and demand in South Africa", LMIP Publication, Human Sciences Research Council, Pretoria.

Life expectancy at birth is defined as the average number of years a newborn can expect to live if they were to pass through life subject to the overall age-specific mortality rates of a given period.[27] Females have a higher life expectancy at birth in comparison to their male counterparts. In 2017, the gap between female and male life expectancy at birth was five years, which is higher than the three-year gap that existed in 2007. The increase in life expectancy at birth results from a reduction in the annual number of registered deaths (Figure 5.1).

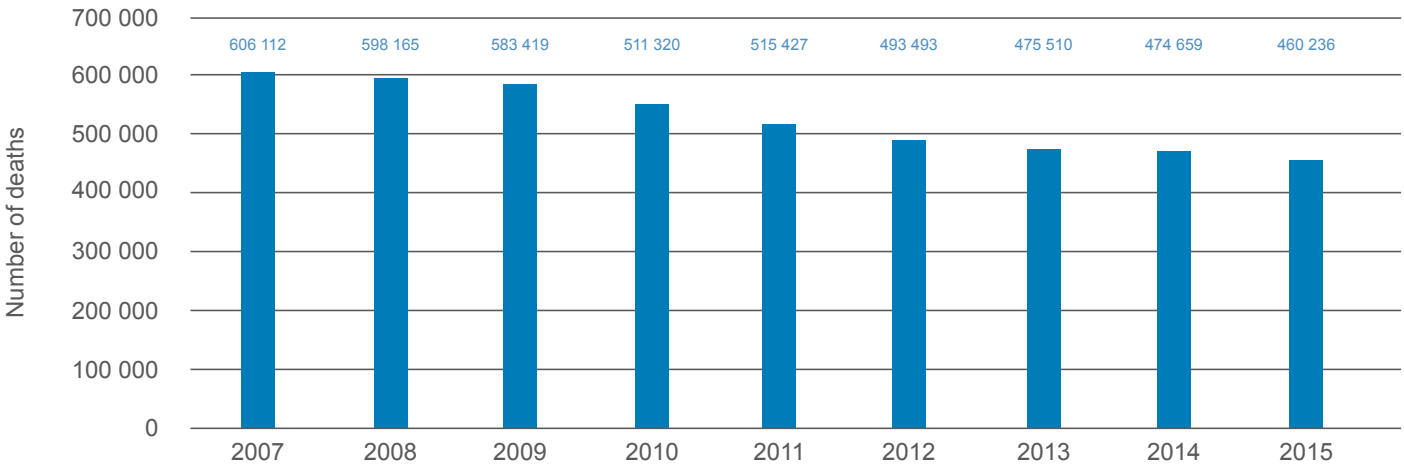


Figure 5.1: *Number of registered deaths by year of death*

Source: Mortality and causes of death in South Africa, 2015: findings from death notification (Statistics South Africa

As shown, the number of deaths declined by one-third from 2007 (606 112 deaths) to 2015 (460 236 deaths). These trends are undoubtedly a function of the decline in the proportion of deaths through AIDS as a successful rollout of free anti-retrovirals has gained momentum since its introduction in 2004. Given that proportionately more females than males have contracted AIDS, the decline in mortality due to AIDS has increased life expectancy among females to a greater extent than among males. The percentage distribution of deaths by sex (Figure 5.2) shows two distinct trends: prior to 2005, in which there was a high rate of female deaths compared with that of males, and since 2005, in which the rate of male deaths increased.

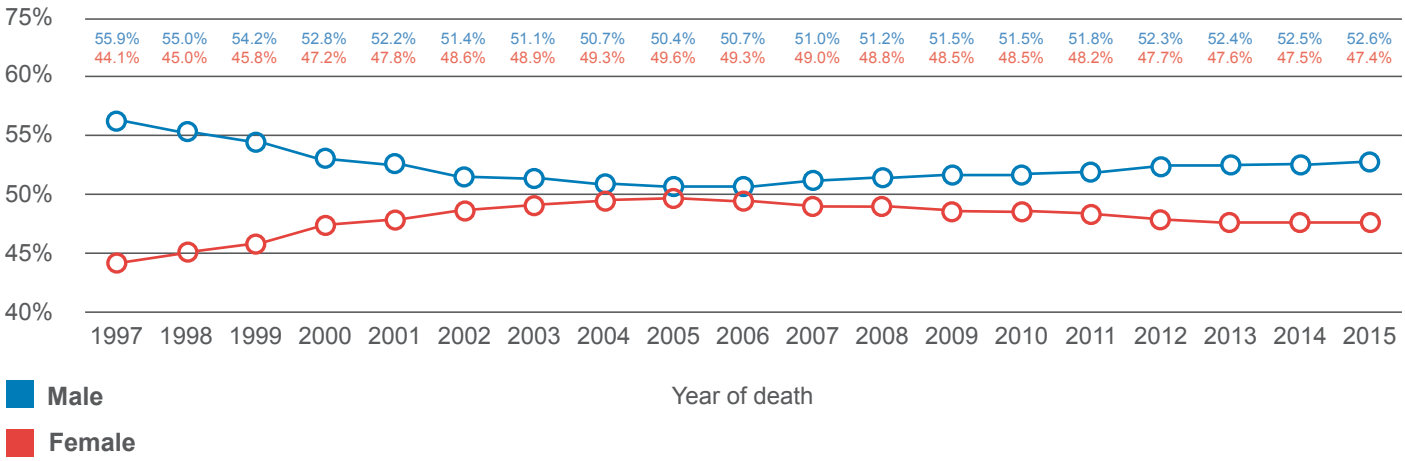


Figure 5.2: *Percentage distribution of deaths by sex and year of death*

Source: Mortality and causes of death in South Africa, 2015 (Statistics South Africa)

It is worthwhile exploring the reasons behind this trend. The underlying leading causes of death are a valuable indicator for this purpose. Table 5.11 shows that the leading underlying cause of natural death is still TB (7.2% of deaths in 2015), although the contribution of TB to deaths in South Africa is on the decline.

27 www.un.org/esa/population/pubsarchive/chart/9.pdf

Table 5.11: *Leading underlying causes of death*

CAUSES OF DEATH	2013	2014	2015
	PERCENTAGE		
Tuberculosis	8.8	8.3	7.2
Diabetes mellitus	4.9	5.0	5.4
Cerebrovascular diseases	4.9	5.1	5.0
Other forms of heart disease	4.7	4.8	4.8
HIV	5.0	4.8	4.8
Influenza and pneumonia	5.1	4.8	4.5
Hypertensive diseases	3.6	3.9	4.2
Other viral diseases	3.0	3.1	3.5
Chronic lower respiratory diseases	2.6	2.7	2.8
Ischaemic heart diseases	…	…	2.7
Intestinal infectious diseases	3.4	3.1	….
Other natural causes	43.6	43.7	44.1
Non-natural causes	10.4	10.7	11.1

Source: Mortality and causes of death in South Africa, 2015: findings from death notification (Statistics South Africa)

Through the expansion of the provision of antiretroviral drugs by government, HIV/ AIDS is becoming more manageable, as it is the fifth leading underlying cause of death. Other diseases that are more fatal than HIV/AIDS are diabetes mellitus, cerebrovascular diseases and other forms of heart disease.

The leading underlying causes of death are different for males and females (Figure 5.3). TB is the leading underlying cause of death for males (8.3% of natural deaths in 2015), followed by HIV/AIDS (4.7%).

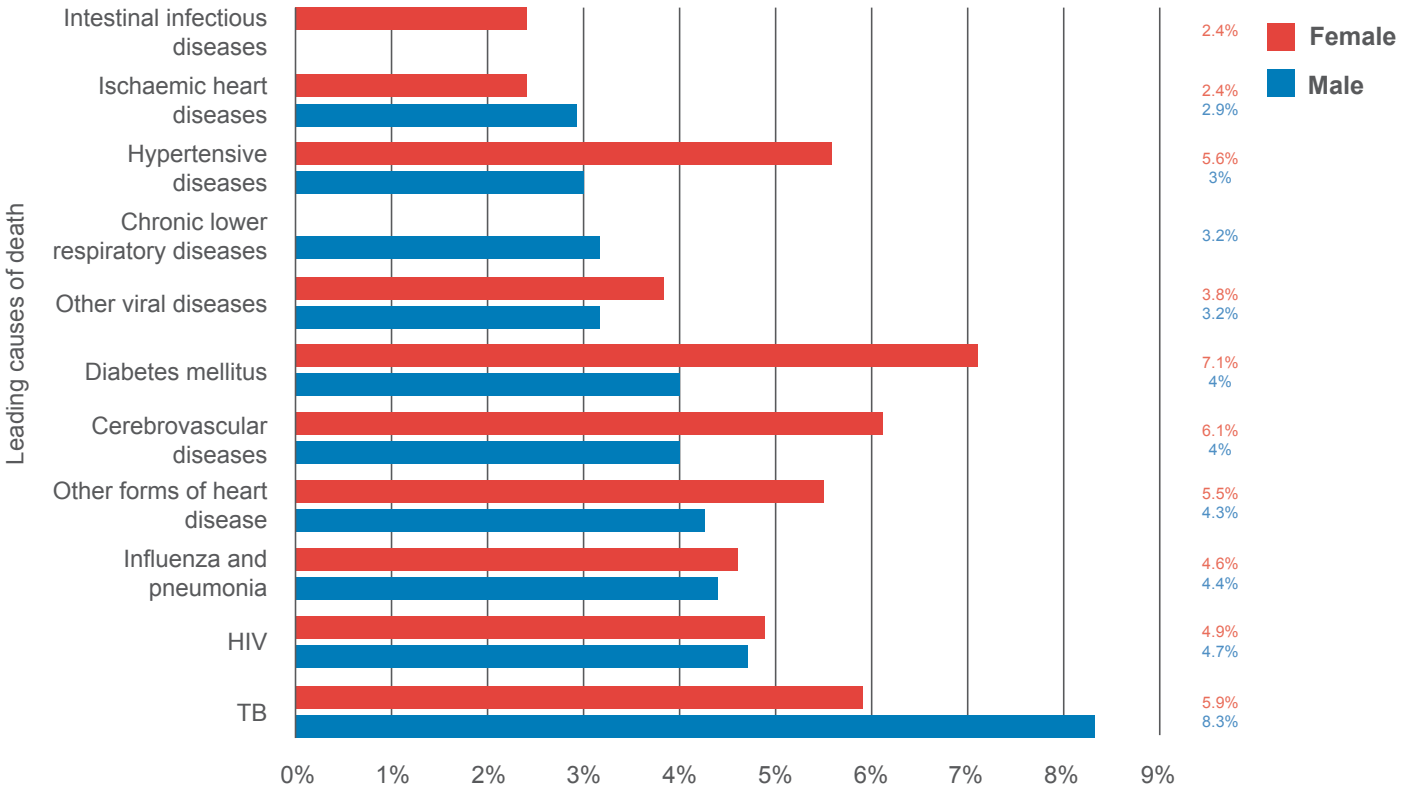


Figure 5.3: *Percentage distribution of deaths by sex and year of death, 2015*

Source: Mortality and causes of death in South Africa, 2015: findings from death notification (Statistics South Africa)

Since TB is not the leading underlying cause of death for females, it could be the driver behind the proportionately higher death rate for males and for the relatively shorter life expectancy for males at birth. TB is a serious challenge in the Southern African mining industry, and in South Africa alone, TB rates in the mining workforce are estimated at between 2 500 and 3 000 cases per 100 000 individuals.[28] According to the World Bank, "this incidence is 10 times the World Health Organisation (WHO) threshold for a health emergency, and is also nearly three times the incidence rate within the general population". Furthermore, "mine workers are at a higher risk of contracting TB due to prolonged exposure to silica dust, poor living conditions, and high HIV prevalence in mining communities". One study[29] has shown a positive correlation between mining production and TB incidence rates. This is a reminder that economic performance does not automatically translate to wellbeing and quality of life.

One of the targets of the Sustainable Development Goals (SDG) is to end the epidemics of HIV/AIDS, TB, malaria and neglected tropical diseases, as well as to combat hepatitis, water-borne diseases and other communicable diseases by 2030. The NRF has established the Centre of Excellence for Biomedical Tuberculosis Research (CBTBR), which is co-hosted by the University of Cape Town, the University of Stellenbosch and the University of the Witwatersrand.

This research centre contributes to local and global research efforts that are aimed at developing new tools for controlling TB and to use the research as a vehicle for training a new generation of high-quality biomedical research scientists.[30] The members of the CBTBR produced 90 and 84 peer-reviewed journal articles in 2016 and 2015 respectively.[31] The knowledge produced by this centre impacts significantly on the local and global efforts of minimising the incidence of TB. More applied research is needed on how to tackle TB and other related epidemics in the South African mining sector.

5.2.3 Social Progress Index

The Social Progress Index addresses three key social issues: does a country provide for its people's essential needs (basic human needs), are the building blocks in place for people to improve their lives (foundations of wellbeing), and is there opportunity for people to improve their position in society (opportunity)?

Table 5.12 shows the ranking of South Africa on the SPI for the past four years. In 2017, the country was ranked 66th out of 128 countries. High inequality levels in South Africa shape the rankings on the three pillars of the SPI. According to Maslow's theory, most of the basic needs should be fulfilled before other human needs of wellbeing and belonging can be fulfilled. The SPI shows the opposite for South Africa, as the country ranks best in respect of opportunity (34th in 2017), followed by foundations of wellbeing (78th). Personal freedom and choice, tolerance and inclusion, as well as personal rights, are key drivers behind a high ranking on opportunity.

28 http://www.worldbank.org/en/programs/the-southern-africa-tb-in-the-mining-sector-initiative
29 Stuckler, D., Basu, S., McKee, M. and Lurie, M (2011) "Mining and risk of tuberculosis in sub-Saharan Africa", *American Journal of Public Health*
30 http://www.nrf.ac.za/division/rcce/instruments/dst-nrf-centre-excellence-biomedical-tuberculosis-research-cbtbr
31 http://www.tuberculosis.org.za/research.htm

Table 5.12: *World ranking of South Africa on the SPI*

COMPONENT	SUB-COMPONENT	2014	2015	2016	2017
		OUT OF 132	OUT OF 133	OUT OF 133	OUT OF 128
Basic human needs	Nutrition and basic medical care	95	89	87	83
	Water and sanitation	85	72	84	80
	Shelter	71	82	86	88
	Personal safety	128	129	129	123
	Sub-component ranking	**94**	**92**	**92**	**90**
Foundations of wellbeing	Access to basic knowledge	59	61	84	84
	Access to information and communication	41	44	44	44
	Health and wellness	129	114	126	110
	Environmental quality	92	75	70	77
	Sub-component ranking	**71**	**64**	**81**	**78**
Opportunity	Personal rights	32	33	36	37
	Personal freedom and choice	50	35	27	33
	Tolerance and inclusion	42	48	25	36
	Access to advanced education	71	72	49	55
	Sub-component ranking	**40**	**37**	**31**	**34**
Social progress ranking		**69**	**63**	**59**	**66**

Source: Social Progress Index (Social Progress Imperative)

Access to advanced education, one of the components of the opportunity pillar, includes indicators such as access to world-class universities. According to the 2017 academic ranking of world universities, the top five South African universities (University of the Witwatersrand, University of Cape Town, University of Stellenbosch, University of Johannesburg and University of KwaZulu-Natal) were in the top 500.

Health and wellness is the weakest link among the foundations of wellbeing. This component includes indicators such as life expectancy at 60 years (107th in 2017), premature deaths from non-communicable diseases (110th) and the suicide rate (100th). A component that is ranked poorly in basic human needs is personal safety (123rd). It includes indicators such as the homicide rate (124th in 2017), level of violent crime (119th), perceived criminality (89th), potential terror (73rd) and traffic deaths (99th). Nutrition and basic medical care has shown gradual improvements from 2014 to 2017, although the number of deaths from infectious diseases is still a major issue for this component.

6. KEY THEMES IN SOUTH AFRICAN STI POLICY

This chapter discusses the key themes that influence South African STI policy: the Fourth Industrial Revolution, public sector innovation, and local innovation systems. The focus on these topics is to draw attention of the policy makers and other National System of Innovation (NSI) stakeholders to the changing global and national innovation landscape.

6.1 FOURTH INDUSTRIAL REVOLUTION

The Fourth Industrial Revolution is one of the global megatrends that is shaping the industrial, academic and policy debates around the evolving new forms of industrial production that are influenced by various emerging technologies. This concept emerged in Germany and was defined as part of the formulation of high-technology strategy in 2012 as a project for the future. The Industry-Science Research Alliance and the German Academy of Science and Engineering (Acatech)'s 2013 final report of the Industry 4.0 Working Group provides recommendations for the implementation of Industry 4.0.

6.1.1 State of investment in converging emerging technologies

For a long time, South Africa has been investing in emerging research areas such as robotics, artificial intelligence, nanotechnology, biotechnology and advanced manufacturing. Several strategies and technology roadmaps guide government's investment in these multiple emerging technologies that are associated with Industry 4.0.

Table 6.1 shows the number of research publications with South African authors in particular research topics, the number of relevant publications worldwide, their South African shares and relevant activity indices. Activity indices show that only research related to the Internet of Things is just above the world or mean standard. All other activity indices are below 1, revealing a lack of emphasis in the relevant fields of research.

It should be noticed that nanotechnology and robotics are the topics with the highest number of publications (322). However, the topics are of international interest, and hence their activity indices are very low.

At this point, it should be emphasised that neither the DST nor the NRF (the major agency in the country) has announced any disciplinary priorities. The NRF was supporting nanotechnology research until recently.

Table 6.1: *South African share in world publications (2006–2016) and activity indices: Industry 4.0 disciplines*

TECHNOLOGY	SOUTH AFRICA	WORLD	SHARE	ACTIVITY INDEX
Robotics	322	190 965	0.16	0.30
Artificial intelligence	140	30 685	0.45	0.86
Internet of Things	79	14 039	0.56	1.07
3D printing	38	8 689	0.43	0.82
Autonomous vehicles	164	41 703	0.39	0.75
Quantum computing	203	58 097	0.34	0.65
Nanotechnology	2928	996 083	0.29	0.55
All disciplines	**204 515**	**39 176 830**	**0.52**	

Table 6.2 shows the number of relevant publications during the most recent years, and the total during the period 1996–2016. As was expected, most of the publications were produced during the most recent years.

Table 6.2: *Number of publications: Industry 4.0 disciplines*

	AUTONOMOUS VEHICLES	ROBOTICS	QUANTUM COMPUTING	ARTIFICIAL INTELLIGENCE	INTERNET OF THINGS	3D PRINTING	NANO-TECHNOLOGY
1996–2016	164	322	203	140	80	36	2 928
2016	37	53	23	31	38	16	N/A
2015	26	43	21	15	23	7	597
2014	23	39	26	16	9	4	521
2013	22	44	19	13	<9	<4	456
2012	<11	<39	<14	<12			343

Table 6.3 shows the most research prolific organisations in the topics under investigation. The University of KwaZulu-Natal appears at the top of the list in four of the seven topics. It should be noted that the relatively small numbers and small differences make the rankings statistically insignificant.

Table 6.3: *Most prolific research producers*

AUTONOMOUS VEHICLES	ROBOTICS	QUANTUM COMPUTING	ARTIFICIAL INTELLIGENCE	INTERNET OF THINGS	3D PRINTING	NANO-TECHNOLOGY
UKZN 25	UKZN 55	UKZN 63	UKZN 23	UP 18	SU. 19	CSIR 479
UCT 20	CSIR 54	SU 30	UP 21	CSIR 14	Wits 4	Wits 416
UP 19	UCT 46	Wits 22	UJ 19	UWC 11	CUT 3	NRF 397
CSIR 15	UP 44	UCT 20	UCT 15	Unisa 10	<3	UJ 381

CSIR: Council for Scientific and Industrial Research; CUT: Central University of Technology; SU: University of Stellenbosch; UCT: University of Cape Town; UJ: University of Johannesburg; UKZN: University of KwaZulu-Natal; Unisa: University of South Africa; UP: University of Pretoria; UWC: University of the Western Cape; Wits: University of the Witwatersrand

6.1.2 State of broadband in South Africa

The Fourth Industrial Revolution entails the convergence of cyber-physical systems, building from the Third Industrial Revolution that was inspired by automation through the use of logical controllers. Therefore, ICT is a key component of Industry 4.0. The state of broadband in South Africa is a major focus in ICT, as broadband technologies are the enablers for the effective and efficient utilisation of ICTs. Broadband also enables universal access to ICT services. An affordable broadband connectivity further enables universal access. Various guiding strategies and plans have been developed in South Africa that are aimed at creating enabling conditions for investment in ICTs. The key policy documents that are discussed are the National Integrated ICT Policy White Paper and the ICT Research, Development and Innovation (RDI) Roadmap.

The development of the National Integrated ICT Policy White Paper was facilitated by the DTPS and approved by Cabinet in 2016. The key issues that this policy document addresses are universal service and access, digital innovation, a digital society, ICT infrastructure, fair competition and digital convergence. One of the reasons for the development of this policy framework is to support government's Nine-point Plan to boost economic growth and job creation through the improvement of the ICT infrastructure and broadband rollout.

The ICT RDI Roadmap was developed by the DST and approved by Cabinet in 2013. This roadmap addresses South Africa's low investment in ICT R&D and high dependency on imported ICT goods and services (10% of GDP). The ICT RDI Roadmap serves as an important instrument for a concrete implementation pathway for the 2007 ICT RDI Strategy. This 10-year roadmap suggested, among other implementation pathways, the creation of the Office of Digital Advantage. The ODA is in charge of coordinating stakeholders for ICT R&D project activities.

This is achieved by taking stock of the current funding commitments, negotiating additional investments, advising on the reprioritisation and realignment of current ICT RDI projects, securing data-sharing agreements, and discussing future/pipeline projects that may not be part of current market opportunities.

The National Integrated ICT Policy White Paper suggested the creation of the ICT RDI Investment and Planning Advisory Council, composed of representatives from the ICT quadra helix (government, civil society, business and research institutions). This Council is established to support the ODA and is co-chaired by the DTPS and the DST. Table 6.4 compares the state of South African broadband access with other BRICS countries, as well as Egypt and Nigeria.

Table 6.4: *Benchmarking of South African broadband indicators, 2016*

	SOUTH AFRICA	BRAZIL	CHINA	INDIA	RUSSIA	EGYPT	NIGERIA
Fixed broadband subscriptions per 100 inhabitants	2.8	13.0	22.9	1.4	19.5	5.2	0.01
Mobile broadband subscriptions per 100 inhabitants	58.6	89.5	66.8	16.8	75.0	52.6	21.8
Percentage of households with internet	53.0	52.4	55.5	22.6	-	43.3	15.2
Percentage of individuals using internet	54.0	59.7	53.2	29.5	76.4	39.2	25.7
Mobile cellular subscriptions per 100 people (2015)	159.3	126.6	93.2	78.8	160.0	111.0	82.2

Source: State of broadband 2017: broadband catalysing sustainable development (ITU)

This data shows that more South Africans are able to access the internet (54.0% of the population) than inhabitants of any of the countries included in the comparison, except for Brazil and Russia. A key driver is the large number of mobile cellular subscriptions per 100 people (159.3 in 2015), the second highest after Russia. A key challenge that remains is access to broadband, and this disadvantages the country by not benefiting from ICT diffusion through mobile cellular devices. A much strengthened competition regulation is suggested by the National Integrated ICT Policy White Paper to encourage innovation within the ICT sector.

6.1.3 The implications of Industry 4.0 for South Africa

Industry 4.0 is a new narrative that is not well developed in South Africa. Government has not adopted any policy position for the ideal framework conditions that can drive its implementation. An integrated policy framework that spans various government portfolios would be beneficial in bringing about policy certainty and providing the cohesion of national efforts to bring about a digital evolution.

The World Economic Forum initiated a study to assess the readiness of countries to respond to the changes presented by the Fourth Industrial Revolution. The preliminary results indicate that, on the four selected maturity levels (global leaders, legacy champions, followers and high potential), South Africa is classified as a follower.[32] Global leaders have a strong current manufacturing base and are well positioned for the future. Legacy champions have a strong current manufacturing base, but are at risk for the future. Followers have a limited current manufacturing base, but are underprepared for Industry 4.0 and are at risk for the future. High-potential countries have a limited current manufacturing base, but are well positioned for the future.

The dti is contemplating developing a Fourth Industrial Revolution Strategy in conjunction with key private and public role players to address challenges and opportunities brought about by the Fourth Industrial Revolution.[33] Furthermore, the dti is planning to develop a policy that will clarify the role of government, the private sector and labour with the hope of devising the interventions that are required to make South Africa more competitive in the global economy.

32 http://m.engineeringnews.co.za/article/the-fourth-industrial-revolution-is-upon-us-and-south-african-industry-must-adapt-2017-10-27
33 http://www.dti.gov.za/industrial_development/fipt.jsp

6.2 PUBLIC SECTOR INNOVATION

While it is recognised that the private sector is the best platform through which the benefits of innovation can be realised, public sector innovation ensures that the benefits of innovation are enjoyed by all citizens, irrespective of their income and social status. Public sector innovation improves the efficiency and effectiveness of government services, and makes public goods accessible at affordable prices.

6.2.1 Framework for the public sector innovation

There are various frameworks for public sector innovation. An example is the OECD's 2015 framework. This framework takes into account a reduction in public sector employment due to reforms implemented by various countries (including South Africa) and low confidence in national governments since the start of the global economic recession. This framework has four pillars of building innovative capacity across the public sector: focusing on the people involved, focusing on the information they are using, focusing on the rules and processes that govern their work, and focusing on the way in which they are working together.

The South African framework for public sector innovation is guided by the Centre for Public Service Innovation, which is mandated to develop innovative, sustainable and responsive models for improved service delivery. The CPSI adopted the following definition of public sector innovation: "the creation and implementation of new and service delivery solutions (systems, processes, methods, models, products and services) resulting in significant improvements in outcomes, efficiency, effectiveness and quality".

6.2.2 Examples of public sector innovations in South Africa

Innovations in South Africa's public sector are typically showcased annually through the CPSI awards. The following are the categories of CPSI Public Sector Innovation Awards:

- **Innovative solutions saving government money:** This category celebrates efforts of public servants to improve the quality and/or speed of services at lower costs and/or simplifying processes to reduce costs.
- **Innovative use of ICTs for effective service delivery:** This category celebrates innovative use of ICTs to improve the efficiency and effectiveness of service delivery with emphasis on the interface with citizens.
- **Innovative service delivery institutions:** This category celebrates institutions and teams delivering services to citizens who find innovative solutions to persistent challenges in schools, hospitals, clinics, courts, police stations and similar institutions.
- **Innovative enhancements of internal systems of government:** This category awards internal institutional innovations that improve back-office systems and processes, both ICT and non-ICT.

According to the CPSI, category winners compete for the coveted Public Sector Innovator of the Year Award. The qualifying finalists are also entered into prestigious international awards, such as the United Nations Public Service Awards.

Table 6.5 shows the past category winners and the Public Sector Innovator of the Year Award winners for 2016, 2015 and 2014. It is clear from this information that critical innovations in the public sector take place at the provincial level. This is not surprising, as it is the provincial governments that are at the coalface of service delivery. These innovations take place in various government service delivery sectors, such as health, roads and transport, education and food security. There are also innovations in the area of collecting government revenue efficiently, as demonstrated by the Limpopo Provincial Treasury's Revenue Enhancement Strategy and the Gauteng Department of Roads and Transport's Revenue Information Management System (RIMS).

Table 6.5: Past winners of the Public Sector Innovation Award

	INNOVATIVE SOLUTIONS SAVING GOVERNMENT MONEY	INNOVATIVE USE OF ICTS FOR EFFECTIVE SERVICE DELIVERY	INNOVATIVE SERVICE DELIVERY INSTITUTIONS	INNOVATIVE ENHANCEMENTS OF INTERNAL SYSTEMS OF GOVERNMENT	PUBLIC SECTOR INNOVATOR OF THE YEAR
2016	Saving lives, saving blood, **Edendale Hospital, Department of Health, KwaZulu-Natal**	Road Accident Fund Enterprise Quality Management Software (EQMS), **Road Accident Fund**	Contractor development, **Free State Department of Police, Roads and Transport**	Revenue Enhancement Strategy, **Provincial Treasury, Limpopo**	Revenue Enhancement Strategy, **Provincial Treasury, Limpopo**
2015	Workplace delivery of medication, **Port Shepstone Provincial Hospital, KwaZulu-Natal**	Sunward Park High School e-learning project, **Sunward Park High School, Gauteng**	The one-stop shop, **Department of Health Gauteng**	Revenue Information Management System, **Department of Roads and Transport, Gauteng**	Workplace delivery of medication, **Port Shepstone Provincial Hospital, KwaZulu-Natal**
2014	Diesel Jojo tanks, **Department of Public Works, Limpopo**	Digital pen for health, **Department of Health, KwaZulu-Natal**	Community food production units, **Department of Agriculture and Rural Development, Gauteng**	Case management and community empowerment, **Tembisa Hospital, Gauteng**	Diesel Jojo tanks, **Department of Public Works Limpopo**

Source: Centre for Public Service Innovation

6.3 LOCAL INNOVATION SYSTEMS

South Africa is a developing country, comprising nine provinces. It is a resource-intensive economy, with a diversity of natural resources that contribute remarkably to its economic growth through mining, agricultural activities, manufacturing and various services. Each province has its own strengths. These are mainly influenced by the geography of the region. It is therefore imperative that regional and local innovation strategies should be based on these strengths and relative advantages. Hence, smart specialisation, a place-based approach characterised by the identification of strategic areas for intervention based on analysing the strengths and potential of the economy and on an entrepreneurial discovery process (EDP) with wide stakeholder involvement,[34] is discussed. It is outward-looking and embraces a broad view of innovation, including but certainly not limited to technology-driven approaches, supported by effective monitoring mechanisms.

Local and regional innovation systems provide a conducive environment for the development of innovation clusters and for sectoral systems of innovation. This section explores the state of South Africa's provincial systems of innovation in terms of the relevant strategies, initiatives and STI indicators.

6.3.1 Gauteng Innovation and Knowledge Economy Strategy

The 2012 Gauteng Innovation and Knowledge Economy Strategy begins by explicitly recognising the importance that must be attached to socially oriented innovations. At the same time, it recognises that individuals, as well as communities, are sources of innovation, and provide direction as to how, why and where the province should be supporting innovation. It also assists in understanding the benefits that can arise from innovation.

This strategy seeks to accelerate innovation in all its forms in order to bolster and support the broader strategic objectives of sustainable social and economic development, and sustainable employment. It is implemented through three main objectives: economic competitiveness, public-sector efficiency and community-led innovation.

The following are some key interventions under the economic competitiveness strategic objective:

- The creation of an Industrial Innovation Unit (IIU) located at The Innovation Hub to focus on industrial design and innovation. This will increase the global competitiveness of local industry by supporting innovation in manufacturing processes, industrial design and logistics.

34 http://s3platform.jrc.ec.europa.eu/what-is-smart-specialisation-

- Support for the establishment of rigorous standards, criteria and regulations for innovative products in strategic industries (for example solar water geysers). Furthermore, the intention is to understand and make representations to the South African Bureau of Standards (SABS) regarding international standards and to support local industries through the IIU.

The following is one of the key interventions under the public sector efficiency strategic objective:

- Investigation of the mechanisms for public-sector procurement of innovation in order to accelerate service delivery with the best and most efficient solutions possible. This would entail understanding and evaluating public regulations regarding the procurement of innovations and novel products, and suggesting amendments for transparent procurement.

The interventions under the community-led innovation strategic objective are the identification of alternative economic value chains that will provide innovative solutions to address social challenges in communities (for example food security and job security). They also include identifying community-developed innovative solutions and fostering the massification of those solutions through replication and incubation, particularly in the townships.

Gauteng hosts leading research institutes and is the centre of higher-level education, providing 40% of tertiary education in the country, as well as a number of business services. This makes it a knowledge-intensive region. It also hosts a number of key institutions, all the national government departments, the CSIR, the ARC, the Onderstepoort Veterinary Institute and various universities, as well as The Innovation Hub, Africa's first internationally accredited science park and a subsidiary of the Gauteng Growth and Development Agency (GGDA), an agency of the Gauteng Department of Economic Development (GDED). The Innovation Hub seeks to incubate innovative new companies so as to enhance the synergy between industry, academia and public institutions.

Table 6.6 shows the indicators that summarise the state of innovation in Gauteng. The province is still contributing significantly to South African R&D expenditure (45.4% in 2015/16), although its proportional contribution to GERD has been on the decline (from 52.2% in 2008/09). This is also the case for the business and science councils.

The proportion of R&D expenditure by state-owned enterprises, not-for-profit organisations and higher education institutions has been increasing following some years of decline.

Table 6.6: *Gauteng R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	9 621	10 982	10 377	9 773	10 391	10 602	11 976	13 887	16 666
Gauteng expenditure on R&D as a percentage of GERD	51.7	52.2	49.5	48.3	46.8	44.4	46.7	46.6	45.4
BERD (million R)	6 142	7 131	6 120	5 440	5 558	5 357	5 814	7 160	7 184
Percentage of business R&D	57.2	57.8	54.9	54.1	53.1	50.7	49.3	53.9	52.0
Percentage of state-owned entities' R&D expenditure	88.2	87.7	74.3	69.4	69.5	67.1	62.9	71.7	79.0
Percentage of not-for-profit organisations' R&D expenditure	51.7	52.4	55.3	37.8	40.6	32.3	30.1	37.0	38.8
Percentage of government R&D expenditure	25.4	23.2	37.1	33.9	36.2	29.7	40.7	40.2	41.4
Percentage of science councils' R&D expenditure	62.7	63.5	64.2	64.7	61.3	63.0	71.2	54.9	52.2
Percentage of higher education R&D expenditure	34.8	35.0	30.1	29.5	30.7	28.9	30.6	32.6	33.5

Source: National Survey of Research and Experimental Development (HSRC and DST)

6.3.2 Limpopo Integrated Innovation Strategy

The Limpopo Integrated Innovation Strategy (LIIS) is focused on the firms (the formal economy), the informal economy, government, academic institutions, science councils and non-profit organisations (NPOs). It plans to make existing agencies the champions of innovation. The formal economy consists primarily of the private sector and government services, and provides funding instruments to the academic institutions in exchange for skills and knowledge sharing. The informal economy, which is mainly community-based, provides human capacity (personnel), while also being positioned to diffuse technologies originating from other components of the system to the end users. The government acts as the main funding and coordinating body for all the stakeholders in the system.

The strategy intends to exploit public resources in order to strengthen existing innovations or to bring them to regions in which they are not yet established. There are also indications of the presence and implementation of numerous successful innovations in sectors such as agriculture (high-yielding cultivars, irrigation, "fertilizer trees") and mining. However, dissemination and facilitation of their adoption by society's most marginalised members has become a huge challenge as some community members do not even know what innovation is. Therefore, the strategy emphasises the need to involve a large number of stakeholders, including intermediaries such as NGOs and community-based organisations. The strategy has the following focus areas:

- Overcoming the relative lack of skilled participants
- Providing access to markets
- Expanding renewable energy resources
- Connecting indigenous knowledge systems with markets, for example organic farming
- Increasing investment in innovation-driven markets and existing innovation agencies or intermediaries rather than in new institutions
- Improving collaboration and partnerships between state, business, communities and academic institutions, including international cooperation and strategic partnerships

Furthermore, the strategy seeks to engage in the following activities:

- Conducting campaigns to showcase the importance of innovation
- Showcasing examples of successful innovations to share lessons
- Mainstreaming innovation into public policy
- Inspiring interprovincial learning networks to strengthen regional innovation systems within the NSI

The following impediments to the Limpopo regional innovation system have been identified:

- Limpopo is generally an under-resourced province.
- Government is poorly equipped to support and coordinate the innovation system.
- The province is "remote" from the country's commercial centres.
- Limpopo is characterised by poor academic and educational performance levels (school pass rates are consistently below the national aggregates). It also has insufficient R&D capacity. As a result, academic institutions are most likely to be active in the dissemination of knowledge rather than in developing new technologies.
- It has infrastructural constraints, such as limited access to electricity, water and ICT.
- Compared to Gauteng and the Western Cape, formal innovation activities in Limpopo are marginal and insufficient to drive the regional innovation system.
- There is limited collaboration and partnerships among stakeholders.
- When benchmarked against other regional and international competitors, Limpopo is less competitive in terms of innovation and absorptive capacity.

Limpopo's R&D expenditure was only R629 million in 2015/16. This is about 1.9% of South African R&D expenditure. Businesses' R&D expenditure, as a percentage of the province's R&D expenditure, was only 23.2%, which implies that STI activities in the province are mainly based in the public sector (Table 6.7).

Table 6.7: *Limpopo R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	241	264	286	340	395	584	619	444	629
Limpopo R&D expenditure as a percentage of GERD	1.4	1.4	1.6	2.0	2.6	2.6	1.7	2.1	1.9
BERD (million R)	72	76	49	42	63	127	140	161	146
Percentage of business R&D expenditure	0.7	0.6	0.4	0.4	0.6	1.2	1.2	1.2	1.1
Percentage of state-owned entities' R&D expenditure	0.0	0.0	0.0	0.4	1.2	1.3	1.2	0.9	0.2
Percentage of NPOs' R&D expenditure	2.1	2.1	2.4	2.8	4.4	2.3	2.4	6.4	6.3
Percentage of government's R&D expenditure	3.5	4.8	5.7	5.7	5.3	5.2	5.6	4.4	4.2
Percentage of science councils' R&D expenditure	2.3	2.0	2.3	1.8	2.7	2.6	0.2	2.3	1.9
Percentage of higher education R&D expenditure	2.2	2.1	2.9	4.1	5.3	4.1	2.6	2.6	2.3

Source: National Survey of Research and Experimental Development (HSRC and DST)

6.3.3 Western Cape Innovation Strategy

The Western Cape Innovation Strategy is focused on maintaining a balance between the top-down and bottom-up participatory approaches, and emphasis has been placed on the need to do the following:

- Create models for innovation sustainability
- Develop strong leadership or champions that will drive and coordinate broad-based innovation
- Develop and define innovation in the South African context
- Promote collaboration at both regional and national level (this may be in the form of iconic systems such as science parks)
- Develop a national innovation strategy that will also acknowledge the cultural diversity and values of our country
- Diversify the economic markets through a novel manufacturing sector using social innovation
- Build knowledge capacity, not only through academic qualifications, but in a form that includes existing indigenous knowledge
- Balance the social and technological elements of innovation

The province is host to several universities, including the University of Cape Town and the University of Stellenbosch, which are ranked among the top 500 universities in the world. These two universities contribute significantly to the overall knowledge generation of South Africa, hence it is not surprising that 31.8% of the higher education sector's R&D expenditure originated from the Western Cape in 2015/16, an increase from 27.3% in 2011/12 (Table 6.8). The government and science councils also have a significant presence in the province as shown by the fact that about 20% of the province R&D expenditure is in these sectors.

Table 6.8: *Western Cape R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	3 373	3 657	4 070	4 425	4 233	4 124	4 555	4 949	5 814
Western Cape R&D expenditure as a percentage of GERD	19.6	19.3	21.1	20.9	18.6	19.1	19.3	19.8	22.0
BERD (million R)	1 755	1 908	2 029	1 723	1 514	1 434	1 512	1 684	2 275
Percentage of business R&D expenditure	17.8	16.3	15.5	18.2	17.1	14.5	13.6	12.8	12.7
Percentage of state-owned entities' R&D expenditure	6.6	7.2	14.6	16.9	7.4	10.1	11.1	5.1	6.0
Percentage of NPOs' R&D expenditure	17.6	17.7	11.4	14.7	12.4	10.9	14.2	10.3	11.3
Percentage of government's R&D expenditure	32.6	32.9	21.9	23.4	19.3	23.2	20.5	20.1	18.8
Percentage of science councils' R&D expenditure	15.3	15.3	15.6	16.1	14.7	14.0	14.1	18.3	21.5
Percentage of higher education R&D expenditure	28.8	30.2	31.4	30.8	27.3	29.6	32.9	32.9	31.8

Source: National Survey of Research and Experimental Development (HSRC and DST)

Although the Western Cape's BERD, as a proportion of the province's total R&D expenditure (39.1% in 2015/16), is lower than that of Gauteng (43.1%), it has a strong focus on technology transfer and the growth of high-technology start-ups. The University of Stellenbosch's university-industry interaction and innovation company, Innovus, has successfully spun out several companies, such as Bridgiot (Pty) Ltd, CUSTOS Technologies (Pty) Ltd, Katleho Biomedical (Pty) Ltd, Sun Magnetics (Pty) Ltd and The Stellenbosch Nanofiber Company (SNC). Innovus also has an incubator, LaunchLab, which functions as a business accelerator and boosts entrepreneurship on campus by providing networking opportunities, mentoring and affordable rental rates in an entrepreneur-friendly environment.[35]

There are many other technology incubators and accelerators in the province. According to the 2017 Venture Capital Survey, investors operating from Gauteng and the Western Cape dominate the Southern African venture capital asset class. Furthermore, this survey found that the Western Cape represents the largest number of deals in the active venture capital portfolio, with Gauteng recording the greatest value of venture capital fund managers invested in active venture capital portfolios.

6.3.4 Eastern Cape Provincial Development Plan

The Eastern Cape Provincial Development Plan aims to achieve the following goals by 2030: an inclusive, equitable and growing economy for the province, an educated, innovative and empowered citizenry, a healthy population, vibrant and equity-enabled communities, and capable agents across government and other institutional partners committed to the development of the province. R&D and innovation are important enablers to achieve these goals, as they are embedded in the four identified catalytic flagships for the realisation of the objectives of this provincial plan: Llima Labantu, Ematholeni, Infrastructure, and Human and Institutional Capabilities.

Llima Labantu is an agricultural development initiative that aims to revive the rural economy and encourage other areas of development in the province. This will be achieved through coherent programmes in the areas, such as agricultural R&D capability development, building capability at education and training institutions, and adequate resourcing of Llima Labantu initiatives. The Ematholeni (children first) initiative aims to give all children a quality start to development and learning, providing a solid foundation for a future of equal opportunity. NACI has highlighted the importance of early childhood development (ECD) as a foundation for building a healthy SET human capital pipeline. The Infrastructure initiative includes social infrastructure (human settlements and public institutions) and economic infrastructure (irrigation systems, factories, production technology, equipment and systems, and ICT). Lastly, the Human and Institutional Capabilities initiative aims to build human and institutional capabilities for inclusive and meaningful local development action.

Table 6.9 shows that the Eastern Cape's R&D expenditure level is very low (6.6% of GERD in 2015/16) in comparison to its 12.6% proportion of the South African population, as reported in the 2015 mid-year population estimates. The two sectors whose R&D expenditure is slightly higher are the government and the higher education sectors (11.2% and 9.9% respectively in 2015). Government's R&D activities in the Eastern Cape include the South African Environmental Observation Network (SAEON) Elwandle Coastal Node, located at the Nelson Mandela University (NMU). In addition to NMU, the University of Fort Hare, Rhodes University and Walter Sisulu University are also located in the Eastern Cape. These four universities lack fully fledged engineering and health science faculties. This is also the case for most of other HDI universities.

Table 6.9: *Eastern Cape R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	827	889	1 121	1 049	1 279	1 464	1 479	1 734	2 143
Eastern Cape expenditure on R&D as a percentage of GERD	4.4	4.2	5.4	5.2	5.8	6.1	5.8	5.9	6.6
BERD (million R)	283	316	321	218	355	468	646	608	652
Percentage of business R&D expenditure	2.6	2.6	2.9	2.2	3.4	4.4	5.5	4.6	4.7
Percentage of state-owned entities' R&D expenditure	0.0	0.0	0.0	0.4	1.2	1.3	1.2	0.9	0.2
Percentage of NPOs' R&D expenditure	2.8	2.8	4.3	6.0	5.6	5.1	4.4	3.5	2.4
Percentage of government's R&D expenditure	10.6	9.5	9.4	11.3	10.3	13.5	7.9	12.0	11.2
Percentage of science councils' R&D expenditure	4.8	5.5	4.5	4.2	4.8	4.5	2.7	5.2	4.7
Percentage of higher education R&D expenditure	7.6	6.8	10.5	10.3	9.2	8.1	7.6	7.3	9.9

Source: National Survey of Research and Experimental Development (HSRC and DST)

35 http://www.innovus.co.za/launchlab-1.html

As the Eastern Cape has the fourth-largest provincial manufacturing sector in South Africa after Gauteng, KwaZulu-Natal and the Western Cape,[36] its BERD, as s percentage of the total provincial R&D expenditure (30.4% in 2015/16), is slightly higher than in some of the other more rural provinces.

This province's manufacturing sector is largely driven by the automotive industry. The Eastern Cape is home to four of the seven original equipment manufacturers (OEMs) operating in South Africa, and it manufactures half of the country's passenger vehicles. It also provides 51% of South Africa's vehicle exports.[37] The automotive manufacturers in the Eastern Cape are concentrated in the Coega Industrial Development Zone.

6.3.5 KwaZulu-Natal Growth and Development Strategy

This strategy maps a way to achieve KwaZulu-Natal's 2035 vision of a prosperous province with a healthy, secure and skilled population, living in dignity and harmony, acting as a gateway to Africa and the world. This vision is further articulated through the following seven strategic goals:

- Inclusive economic growth
- Human resource development
- Human and community development
- Strategic infrastructure
- Environmental sustainability
- Governance and policy
- Spatial equity

KwaZulu-Natal has positioned itself well as a vibrant province economically. Its GDP is the second largest in the country, after Gauteng. This is attributed to a wealth of industrial activities that take place in the province, notably the Richards Bay Industrial Development Zone, King Shaka International Airport, and the Durban, Richards Bay and Dube Trade Ports. These are aimed at attracting both international and local investments, while creating significant and sustainable employment opportunities in manufacturing, export-based and agro-processing industries. Indeed, KwaZulu-Natal's BERD, as a percentage of its total R&D expenditure, was 41.1% during 2015/16 (Table 6.10), a percentage slightly higher than that of the Western Cape (39.1%) for the same year.

That being said, there is much room of improvement for overall R&D expenditure in the province, as in 2017 the population of KwaZulu-Natal made up about 19.6% of the total South African population. The large proportion of R&D expenditure in the NPO sector (26.1% in 2015/16) is above this population benchmark, which shows the importance of civil society for the regional innovation system of KwaZulu-Natal.

Table 6.10: *KwaZulu-Natal R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	2 081	2 210	2 167	2 291	2 516	3 013	2 753	3 187	3 335
KwaZulu-Natal expenditure on R&D as a percentage of GERD	11.2	10.5	10.3	11.3	11.3	12.6	10.7	10.9	10.3
BERD (million R)	1 302	1 256	1 184	1 280	1 161	1 238	1 434	1 501	1 437
Percentage of business R&D	12.1	10.2	10.6	12.7	11.1	11.7	12.2	11.3	10.4
Percentage of state-owned entities' R&D expenditure	0.0	0.0	0.0	0.4	1.2	1.3	1.2	0.9	0.2
Percentage of NPOs' R&D expenditure	18.9	16.8	16.2	22	19.8	32.4	28.6	23.2	26.1
Percentage of government's R&D expenditure	6.6	10.1	5.1	4.8	10.3	11.7	9.5	9.4	9.3
Percentage of science councils' R&D expenditure	7.0	7.4	6.8	6.9	7.8	7.6	5.6	9.7	10.0
Percentage of higher education R&D expenditure	12.7	13.6	13.0	12.5	13.7	15.5	10.3	10.1	9.1

Source: National Survey of Research and Experimental Development (HSRC and DST)

36 http://www.ecsecc.org/documentrepository/informationcentre/wp-20-industrialisationscreen_76132.pdf
37 http://manufacturingindaba.co.za/ec/

Although the University of KwaZulu-Natal is one of the top five universities in the country and is ranked high on the world's top 500 universities, the R&D expenditure of KwaZulu-Natal's higher education sector, as a percentage of the total higher education sector's R&D expenditure, is relatively low (9.1%). KwaZulu-Natal hosts a series of other universities, such as the Durban Institute of Technology, the University of Zululand, Mangosuthu University of Technology and Durban University of Technology.

6.3.6 Free State Innovation Strategy

The revised Free State Provincial Growth and Development Strategy (FSGDS) identifies the following four priority areas of intervention: economic development and employment creation, social and human development, justice and crime prevention, and efficient administration and good governance.

About 14% of the Free State's manufacturing is classified as high technology: the highest of all provincial economies.[38] This is supported by the largest of all the provinces' BERD, as a percentage of the province's R&D expenditure (63.2% in 2015/16). This does not come as a surprise, as the province is a home to Sasol Technology, a subsidiary of Sasol, which is known to employ a large number of scientists and engineers. It should, however, be noted that the BERD in the Free State is on a declining trend in comparison to that of the country (Table 6.11). As a result, the province's total R&D expenditure, as a percentage of GERD, is also on a decline.

Table 6.11: *Free State R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	1 098	1 563	1 371	1 332	1 719	1 714	1 943	1 456	1 778
Free State expenditure on R&D as a percentage of GERD	5.9	7.4	6.5	6.6	7.2	7.2	7.6	5.4	5.5
BERD (million R)	786	1 214	1 000	944	1 309	1 265	1 375	832	1 124
Percentage of business R&D expenditure	7.3	9.8	9.0	9.4	12.5	12.0	11.7	6.3	8.1
Percentage of state-owned entities' R&D expenditure	0.3	0.1	0.8	1.5	2.4	1.9	1.6	1.2	0.5
Percentage of NPOs' R&D expenditure	0.9	0.6	2.0	2.3	3.9	3.0	3.0	2.7	1.8
Percentage of government's R&D expenditure	5.4	5.2	4.3	4.0	3.6	2.7	3.2	3.2	3.1
Percentage of science councils' R&D expenditure	2.4	1.9	2.2	1.7	1.0	1.0	1.1	1.2	1.0
Percentage of higher education R&D expenditure	5.0	5.4	4.8	5.2	4.9	4.9	6.2	5.9	5.3

Source: National Survey of Research and Experimental Development (HSRC and DST)

As the Free State's population and GDP are about 5% of the South African total,[39] its level of R&D expenditure by state-owned enterprises (0.5% in 2015/16), science councils (1.0%), NPOs (1.8%) and government (3.1%) is relatively low. The higher education sector's R&D expenditure for the Free State is slightly above the 5% benchmark. Two public universities, the University of the Free State and the Central University of Technology, are located in the Free State.

6.3.7 Mpumalanga Economic Growth and Development Path

The Economic Growth and Development Path of Mpumalanga captures the key comparative and competitive advantages of the province, economic triggers that will have a positive impact on low-skill labour-absorbing job creation, domestic beneficiation of raw materials, and local content and supply into production processes, growth trajectories that are strategically linked to sustainability and new economies, and strategic interventions (projects, programmes or policies) that will positively support and contribute to Mpumalanga's strategic objectives.

Some STI initiatives that are incorporated into this plan are the upscaling of agricultural research to reverse a declining contribution of the province's agricultural sector to Mpumalanga's economy. Intensified agricultural research will bring benefits such as improved cultivars, improved farming techniques, higher productivity, increased value adding, and agro-processing and skills development. In the manufacturing sector, Mpumalanga seeks to target the sectors that

38 https://mg.co.za/article/2011-11-18-free-state-facts-and-figures
39 https://www.tips.org.za/images/The_REB_Provincial_Review_2016_Free_State.pdf

ensure beneficiation, enhance skills development, especially in the areas of engineering, artisan, business and project management, recruit technology and skills from outside the province as beneficiation requires high-level skills and technology, invest in industrial infrastructure to encourage enterprise development, provide comprehensive support to SMME development, and partner with the DST and other institutions, such as the institutions of higher learning, to research areas of the economy that can benefit communities.

Since Mpumalanga's share of South African population is about 7.9%, its share of the country's R&D expenditure is very low (2.4% in 2015/16). This low level of R&D is prevalent in all sectors (Table 6.12), except for the government sector in which spending on R&D is slightly higher (5.6%).

The relatively low R&D expenditure in the higher education sector is driven by the fact that there is only one university in the province: Mpumalanga University. This university is still new and is not yet providing master's and doctoral degrees.

Table 6.12: *Mpumalanga R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	370	453	379	394	398	523	612	616	859
Mpumalanga expenditure on R&D as a percentage of GERD	2.4	1.8	1.9	2.0	2.4	2.6	2.4	2.9	2.4
BERD (million R)	196	202	161	140	157	223	302	436	340
Percentage of business R&D expenditure	1.8	1.6	1.4	1.4	1.5	2.1	2.6	3.3	2.5
Percentage of state-owned entities' R&D expenditure	0.0	0.0	0.0	0.4	1.2	1.8	1.8	1.7	0.7
Percentage of NPOs' R&D expenditure	4.4	4.3	4.4	8.1	9.4	4.6	4.6	3.9	2.9
Percentage of government's R&D expenditure	6.5	3.4	6.4	6.9	6.3	5.6	4.6	4.9	5.6
Percentage of science councils' R&D expenditure	2.3	1.8	1.9	1.5	2.7	2.6	1.4	2.5	2.1
Percentage of higher education R&D expenditure	2.9	1.7	1.7	2.2	2.6	2.5	2.0	2.1	1.9

Source: National Survey of Research and Experimental Development (HSRC and DST)

Even at undergraduate level, Mpumalanga University's faculties are still being developed. Many SET courses are not yet available. In line with the notion of regional specialisation, there is an urgent need to fully resource the University (infrastructure, human capital and centres of excellence) in order to catalyse the advancement of the province.

6.3.8 Northern Cape Innovation Strategy

Since the Northern Cape's population is only 2.1% of South Africa's total population, its R&D expenditure, as a percentage of the country's GERD, is at the normal level (Table 6.13).

Table 6.13: *Northern Cape R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	181	170	174	218	250	341	401	474	576
Northern Cape expenditure on R&D as a percentage of GERD	0.9	0.8	1.0	1.2	1.5	1.7	1.8	2.0	2.0
BERD (million R)	7	7	8	17	45	78	124	226	207
Percentage of business R&D expenditure	0.1	0.1	0.1	0.2	0.4	0.7	1.1	1.7	1.5
Percentage of state-owned entities' R&D expenditure	0.0	0.0	0.0	0.4	1.3	1.2	3.2	0.9	0.1
Percentage of NPOs' R&D expenditure	0.9	1.0	1.3	1.2	3.7	0.8	0.6	0.2	0.2
Percentage of government's R&D expenditure	5.8	4.6	7.3	5.8	5.1	5.2	3.6	2.8	3.4
Percentage of science councils' R&D expenditure	1.6	1.4	1.0	1.8	2.2	2.0	2.8	3.0	3.8
Percentage of higher education R&D expenditure	1.3	1.6	1.8	2.0	2.2	2.2	2.2	1.8	1.7

Source: National Survey of Research and Experimental Development (HSRC and DST)

However, state-owned enterprises, NPOs, the business sector and the higher education sector have shares of R&D expenditure that are lower than the 2.1% population share benchmark. Similar to the situation in Mpumalanga, the Northern Cape has only one university: Sol Plaatje University. This university is still relatively new. Its lack of master's and PhD courses is not helping to uplift the level of R&D expenditure in the province's higher education sector.

Again, a more vibrant higher education sector can assist the Northern Cape to uplift its economic performance and social progress. The government is performing well in upgrading the innovation capability of the province, as both the government and science councils are spending a relatively high amount on R&D in the Northern Cape. The rising share of science councils' R&D expenditure in the Northern Cape (from 1.0% in 2009/10 to 3.8% in 2015/16) can be directly attributed to the SKA project, an international effort to build the world's largest radio telescope. Other initiatives that are linked to the SKA are the MeerKAT, KAT-7 and the South African Radio Astronomy Observatory.

6.3.9 North West Innovation Strategy

Despite North West's abundance of natural platinum deposits and mines, its country share of R&D expenditure is very low (3.7% in 2015/16) in comparison to its 6.8% country share of the population. That being said, North West's R&D expenditure is showing some improvement, as in 2007/08, its country share of R&D expenditure was only 2.4% (Table 6.14).

Table 6.14: *North West R&D expenditure trend*

	2007	2008	2009	2010	2011	2012	2013	2014	2015
R&D expenditure (million R)	402	454	487	541	532	732	890	1 027	1 403
North West expenditure on R&D as a percentage of GERD	2.4	2.3	2.6	2.6	3.3	3.7	4.0	4.8	3.7
BERD (million R)	193	223	268	256	302	380	436	682	452
Percentage of business R&D expenditure	1.8	1.8	2.4	2.5	2.9	3.6	3.7	5.1	3.3
Percentage of state-owned entities' R&D expenditure	3.4	3.2	6.4	7.0	10.7	10.0	10.0	14.4	8.6
Percentage of NPOs' R&D expenditure	1.0	0.9	2.4	3.4	1.1	8.5	12.4	13.6	11.0
Percentage of government's R&D expenditure	3.7	6.2	2.7	4.3	3.6	3.2	4.3	3.0	3.1
Percentage of science councils' R&D expenditure	1.7	1.3	1.5	1.2	2.8	2.7	0.9	3.1	2.7
Percentage of higher education R&D expenditure	4.6	3.6	3.7	3.4	4.2	4.2	5.6	4.8	4.5

Source: National Survey of Research and Experimental Development (HSRC and DST)

A small share of North West's business expenditure on R&D (3.3% in 2015/16) is driven by the fact that most mining companies in the province conduct their R&D activities elsewhere (mostly in Gauteng). The low percentage share of the province's R&D expenditure in the higher education sector (4.5% in 2015/16) makes sense, as North West has only one public university: North West University (NWU). This university's research capability is well developed and contributes significantly to the country's research and innovation efforts. As an example, the NWU co-hosts HySA Infrastructure's Centre of Competence with the CSIR and it is host to the dti's Centre of Excellence in Advanced Manufacturing.

APPENDIX I

RETURN ON INVESTMENT ON R&D – SELECTED STUDIES

Solow (1957)[40] identified the factors that underlie the doubling in gross output per hour of work that the USA enjoyed between 1909 and 1949. He estimated that, of all factors (capital, labour, savings, etc.), technical change had contributed seven-eighths of the improvement in economic growth. Solow won the Nobel Prize in Economics in 1987 for his studies.

Terleckyj (1977)[41] found the rate of return for manufacturing industries to be 37% on private R&D when only direct R&D inputs were considered.

In a study of 883 companies, representing more than 80% of the entire industrial R&D conducted in the USA, Griliches (1985)[42] found a 17% rate of return to total R&D, private plus government funded, for the period 1957–1965. There was a wide range of rate of return by industry, with the chemical industry at the top at 93%, but electric equipment, and aircraft and missiles at the bottom at 3% to 5%, and metals, machinery and motor vehicles in the middle at 23% to 25%. For privately financed R&D alone, Griliches found a substantially higher average return of 32% to 40%.

Chand (1978)[43] examined the performance of 19 Canadian industries according to the amount they had invested in R&D. He estimated that research-intensive industries over a period of 13 years had a 50% higher growth in output, 29% higher growth in productivity and 56% lower growth in prices than other industries. In comparison with industries that did not undertake research, employment in research-intensive industries grew by 231% more, output expanded by 66% more and there was 43% higher growth in productivity and 57% lower growth in prices.

Mansfield (1980)[44] refined Terleckyj's work on the 20 manufacturing industries by dividing R&D into its basic and applied components. He found a "strong relationship between the amount of basic research carried out by an industry and the industry's rate of productivity increase during 1948–1966". In a further study of 37 innovations, Mansfield (1982)[45] compared the return on R&D for those innovations to the firm making the investment (the "private return") with the return to society as a whole (the "social return"). He found a median private rate of return of about 25%, but a median social return of close to 70%.

40 Solow, R. (1957) "Technical change and the aggregate production function", *Review of Economic Statistics* 39: 312–320.
41 Terleckyj, N.E. (1977) *Estimates of the direct and indirect effects of industrial R&D on economic growth in the state of science and research: some new indicators,* Westview Press, Boulder, CO
42 Griliches, Z. (1985) "Productivity, R&D and basic research at the firm level in the 1970s", National Bureau of Economic Affairs Working Paper Series No. 1547, National Bureau of Economic Research, Cambridge, MA
43 Chand, U.K.R. (1978) "Does R&D boost industrial growth?", *Canadian Business Review* 5(3): 27–31
44 Mansfield, E. (1980) "Basic research and productivity increase in manufacturing", *American Economic Review* 70(5): 863
45 Mansfield, E. (1982) "How economists see R&D", *Research Management* 25(4): 23–29

The Office of Technology Assessment (OTA) (1986),[46] in reviewing the productivity return to agricultural research, concluded that all but one of the studies showed a very high internal rate of return on public-sector agricultural research. The rate of return varied from a low of 21% to a high of 110%, with the vast majority in the 33% to 66% range.

Coe, Helpman and Hoffmaister (1995)[47] of the Centre for Economic Policy Research examined the links between R&D and productivity gains in OECD countries between 1970 and 1990. They concluded that an increase in business R&D increases total factor productivity (the output for a given input of labour and capital) with a response that was related to the total "stock" of R&D from domestic and foreign sources. The rate of return on industrial R&D was over 100% at the national level.

Bernstein (1996)[48] estimated the rates of return to R&D in the Canadian communications equipment industry and the Canadian manufacturing sector. The estimated social rates of return were found to be 22.5% and 24% higher than the private rates of return respectively.

The OECD (1986)[49] found that R&D is beneficial to the creation of employment. A country that lags behind in innovation tends to lose jobs to those countries that lead in the introduction of new technology.

The National Association of Manufacturers (NAM) (1998)[50] identified that tax incentives offered by governments to industrial establishment have a substantial positive effect on the economy.

Econometric simulations run by the NAM assessed the benefits of a 20% tax credit and showed that the economy would be 203% or US$28 billion larger after 20 years than it would have been in the absence of the tax credit. Further, NAM examined the impact of a full 10% credit allowed on annual R&D investments made by companies instead of the incremental credit. The result is that GDP increases by US$174 billion over 20 years. The study, which was submitted to Congress, concluded that increasing the credit on R&D investments would lower the cost of R&D even more, leading to more investment in research, faster gains in productivity and significantly larger gains in GDP.

More recent research by Kafouros (2007)[51] identified that R&D also drives significant organisational adaptations that favour business performance.

46 OTA (1986) "Research funding as an investment: can we measure the returns?" Congress of the USA, Office of Technology Assessment
47 Coe, D.T., Helpman, E. and Hoffmaister, A.W (1995) "North-south R&D spillovers", Centre for Economic Policy Research.
48 Bernstein, J.I. (1996) "R&D and productivity growth in Canada: communication equipment and manufacturing" Working Paper No. 10, Industry Canada, Ottawa
49 OECD (1986) "Technology and jobs", *STI Review* 1:9, Coe DT., Helpman E. and Hoffmaister 46
50 NAM (1998) "The R&D tax credit: lasting gains in research and GDP" National Association of Manufacturers, Washington, DC
51 Kafouros, M.I. (2007) "Industrial innovation and firm performance: the impact of scientific knowledge on multinational corporations" Edward Elgar

APPENDIX 2

PROLIFIC COUNTRIES IN BROAD SCIENTIFIC DISCIPLINES 2010–2015

Table A.1: Social sciences

NO.	COUNTRY	TOTAL	PERCENTAGE OF 1 607 118
1	USA	509 069	31.676
2	England	170 222	10.592
3	China	102 420	6.373
4	Australia	78 683	4.896
5	Canada	78 125	4.861
6	Germany	76 666	4.770
7	Spain	50 742	3.157
8	The Netherlands	49 372	3.072
9	France	39 650	2.467
10	Italy	38 840	2.417
11	Sweden	22 618	1.407
12	Switzerland	21 596	1.344
13	Belgium	21 437	1.334
14	Romania	20 456	1.273
15	Japan	20 037	1.247
16	Turkey	19 991	1.244
17	Scotland	19 954	1.242
18	Taiwan	17 113	1.065
19	South Africa	16 443	1.023

Table A.2: Arts and humanities

NO.	COUNTRY	TOTAL	PERCENTAGE OF 884 222
1	USA	212 625	24.047
2	England	81 174	9.180
3	Canada	26 739	3.024
4	Germany	21 933	2.480
5	Australia	18 049	2.041
6	France	17 287	1.955
7	Spain	16 325	1.846
8	Italy	13 990	1.582
9	Scotland	10 830	1.225
10	The Netherlands	9 422	1.066
11	China	8 507	0.962
12	Belgium	6 329	0.716
13	Israel	4 861	0.550
14	Brazil	4 674	0.529
15	Switzerland	4 408	0.499
16	Russia	4 272	0.483
17	Sweden	4 210	0.476
18	Ireland	4 067	0.460
19	South Africa	3 846	0.435

Table A.3: Life sciences and biomedicine

NO.	COUNTRY	TOTAL	PERCENTAGE OF 6 871 042
1	USA	2 158 697	31.417
2	China	541 800	7.885
3	England	498 159	7.250
4	Germany	454 088	6.609
5	Japan	349 851	5.092
6	Canada	315 630	4.594
7	Italy	310 369	4.517
8	France	290 964	4.235
9	Australia	263 090	3.829
10	Spain	240 637	3.502
11	Brazil	202 172	2.942
12	The Netherlands	198 741	2.892
13	South Korea	179 072	2.606
14	India	178 591	2.599
15	Switzerland	129 821	1.889
16	Turkey	126 225	1.837
17	Sweden	114 658	1.669
18	Belgium	99 415	1.447
19	Poland	87 254	1.270
20	Taiwan	82 876	1.206
21	Denmark	82 238	1.197
22	Scotland	72 707	1.058
23	Austria	71 334	1.038
24	Iran	71 252	1.037
25	Russia	57 767	0.841
26	Israel	57 150	0.832
27	Portugal	56 667	0.825
28	Greece	56 080	0.816
29	Norway	54 516	0.793
30	Mexico	49 391	0.719
31	Finland	48 677	0.708
32	Ireland	45 707	0.665
33	Czech Republic	44 551	0.648
34	South Africa	43 831	0.638

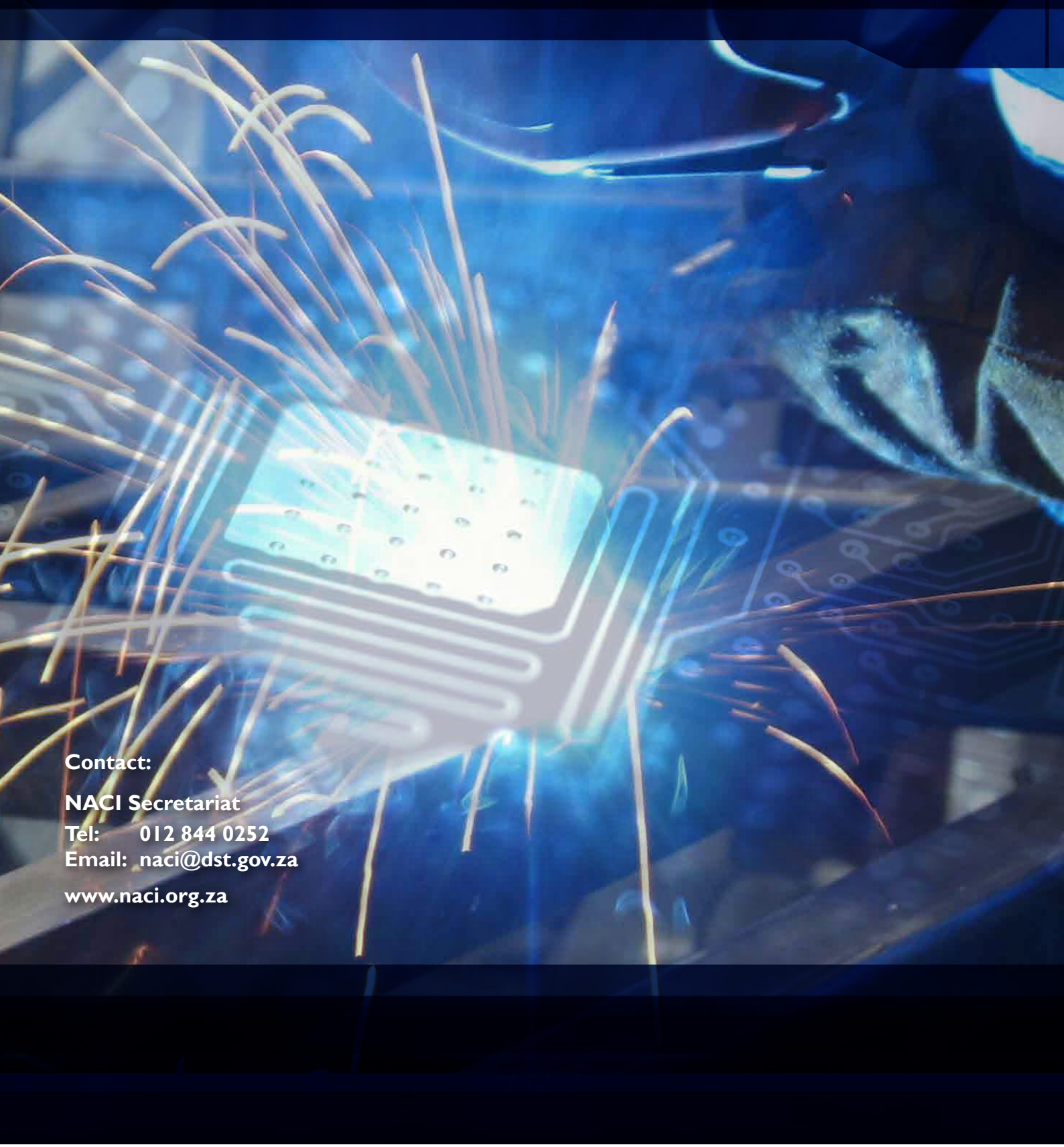
Table A.4: Technology

NO.	COUNTRY	TOTAL	PERCENTAGE OF 3 995 120
1	China	924 293	23.136
2	USA	777 310	19.456
3	Germany	225 248	5.638
4	Japan	205 800	5.151
5	India	184 102	4.608
6	England	175 320	4.388
7	France	173 713	4.348
8	South Korea	153 197	3.835
9	Italy	138 556	3.468
10	Canada	134 627	3.370
11	Spain	118 851	2.975
12	Taiwan	102 911	2.576
13	Australia	101 592	2.543
14	Iran	77 546	1.941
15	Russia	67 043	1.678
16	Brazil	65 052	1.628
17	The Netherlands	64 236	1.608
18	Poland	59 950	1.501
19	Switzerland	52 160	1.306
20	Turkey	51 739	1.295
21	Sweden	49 716	1.244
22	Malaysia	48 648	1.218
23	Singapore	45 496	1.139
24	Belgium	40 651	1.018
25	Portugal	37 683	0.943
26	Czech Republic	35 437	0.887
27	Austria	32 272	0.808
28	Romania	31 522	0.789
29	Greece	29 637	0.742
30	Finland	28 383	0.710
31	Denmark	27 108	0.684
32	Mexico	24 982	0.625
33	Israel	24 697	0.618
34	Saudi Arabia	24 203	0.606
35	Scotland	24 164	0.605
36	Norway	23 245	0.582
37	Egypt	19 767	0.495
38	Thailand	19 758	0.495
39	South Africa	17 244	0.432

Table A.5: Physical sciences

No.	Country	Total	Percentage of 3 262 667
1	USA	729 379	22.355
2	China	647 603	19.849
3	Germany	264 041	8.093
4	Japan	214 496	6.574
5	France	194 431	5.595
6	England	164 253	5.034
7	India	159 653	4.893
8	Italy	139 709	4.282
9	Russia	139 584	4.278
10	Spain	121 746	3.731
11	South Korea	120 735	3.701
12	Canada	108 206	3.316
13	Australia	81 611	2.501
14	Poland	66 684	2.044
15	Taiwan	65 931	2.021
16	Iran	63 443	1.945
17	Switzerland	61 169	1.875
18	Brazil	60 249	1.847
19	The Netherlands	55 694	1.707
20	Turkey	42 797	1.312
21	Sweden	42 069	1.289
22	Belgium	39 738	1.218
23	Czech Republic	35 466	1.087
24	Austria	30 859	0.946
25	Portugal	30 476	0.934
26	Singapore	29 151	0.893
27	Mexico	28 803	0.883
28	Israel	28 273	0.867
29	Scotland	27 385	0.839
30	Romania	26 504	0.812
31	Denmark	25 215	0.773
32	Malaysia	25 014	0.767
33	Saudi Arabia	24 702	0.757
34	Ukraine	23 698	0.726
35	Greece	22 901	0.702
36	Finland	22 772	0.698
37	South Africa	20 202	0.619

NOTES



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