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DEPARTMENT OF SCIENCE AND INNOVATION

NO. 2136 **6 June 2022**

REPORT ON THE REVIEW OF THE HIGHER EDUCATION, SCIENCE, TECHNOLOGY AND INNOVATION INSTITUTIONAL LANDSCAPE

I, Bonginkosi Emmanuel Nzimande, the Minister of Higher Education, Science and Innovation, hereby publish in accordance with section 85 (2) (b) of the Constitution of the Republic of South Africa, the review report of the Higher Education, Science, Technology and Innovation Institutional Landscape, for public comment.

Members of the public are invited to submit their comments/input on this review report within 30 days of the date of the publication of this notice. Written comments may be submitted to:

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Private Bag x894
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Meiring Naude Road
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Attention: Urszula Rust

Email: comments@dst.gov.za

The review report of the Higher Education, Science, Technology and Innovation Institutional Landscape can also be accessed online from www.dst.gov.za

MR BE NZIMANDE, MP
MINISTER OF HIGHER EDUCATION, SCIENCE AND INNOVATION
DATE: 12/05/2022

A New Pathway 2030: Catalysing South Africa's NSI for Urgent Scaled Social and Economic Impact

A Review of South Africa's Higher Education, Science, Technology and Innovation Institutional Landscape (HESTIIL)

Report by the HESTIIL Ministerial Committee

September 2020

Chairperson's message

It was a special privilege and honour for us to respond in December 2019 to the call of the Minister of Higher Education, Science and Innovation, Dr Nzimande, to undertake this review of South Africa's Higher Education, Science and Innovation landscape. Our review followed on the heels of the 2017 Review of the Science, Technology and Innovation landscape. This time though, in the context of the consolidation of the Ministries of Higher Education and Training, and Science and Technology, to form the Ministry of Higher Education, Science and Innovation, our brief was formally extended to incorporate the review of the full spectrum of research entities and universities that fall within the purview of the new ministry. Even then, our review is far more comprehensive and extends to all the country's public research entities and institutions that fall within the purview of other ministries.

The devastating COVID-19 global pandemic and the associated lockdown of the country came just as our work was gathering pace. However, after we had found our 'digital' feet, we were able to progress our work at an unimaginable depth and pace. While we lost out on *in situ* international benchmarking, this was made up through a World Bank-hosted webinar and an extensive and detailed set of virtual engagements with South Africa's research entities, institutions and universities. In the event we consulted with the three leading government departments that sit astride the country's research-innovation-technology-transfer-industrialisation value chain, viz. the Departments of Higher Education and Training, Science and Innovation, and Trade, Industry and Competition. We were also privileged to test and consult our initial findings and views with twenty research entities and institutions, Universities South Africa (USAf) representing the country's twenty-six universities, eight development finance institutions, thirty-six representatives from various business and industry associations and entities, and twenty-three representatives from various civil society organisations. We gleaned immense insights and wisdom from these consultations, all of which have enriched our findings and recommendations.

It is self-evident that our country's adaptive, self-organising and dispersed 'republic of science' has until now successfully evaded coordination. This has had significant consequences for the evolution of our National System of Innovation (NSI), most notably for achieving sustained depth in our areas of current and emergent excellence, and for achieving far greater social and economic yields as required by the National Development Plan 2030. Strikingly, as we show in our report, our research outputs are plateauing at a level that has already placed the country behind China, S. Korea, Malaysia and Singapore and which will soon see Egypt surpassing it. Equally significantly, our patent outputs are already in decline from a low peak. These developments are in part the consequence of the absence of system steering, and of sustained under-investment in our research, development and innovation (RDI) enterprise that will require focused remediation over the next decade. It is also the consequence of the over-concentration of the RDI enterprise in historically advantaged institutions where the development of inclusive, diverse, pluralistic and non-patriarchal knowledge-producing research communities and cultures have proved extraordinarily sticky.

Our overarching recommendation is that the RDI enterprise should be expanded in a planned and coherent manner. This will over the next decade require a doubling of investments from the state, business and industry. It will also require the focused, coherent and progressive pivoting of existing incentives – viz., input and output grants, transfers and taxation – to support the achievement of capacity, depth and far greater social and economic outputs. In order for the latter to be successfully achieved, a common language should be nurtured and socialised across the NSI. We are particularly optimistic about the country's prospects, more so in light of its COVID-19 global pandemic response demonstrates that the borders separating deeply siloed government departments, business and industry, and the country' leading science organisations and scientists can be crossed in service of

providing a comprehensive response and programme of action. It is precisely this cross-governmental, cross-research entity, cross-business and industry and cross-civil society approach that will be essential if we are to coherently expand and deepen our NSI in the service of our nation.

We were able to undertake and complete our work because of the exceptional support provided by Dr Phil Mjwara, Director-General of Science and Innovation, and his amazing team of colleagues. In this regard, we are especially indebted to Ms Nthabiseng Msomi for her complete dedication to our work and her outstanding support. We are also grateful to Ms Thandeka Mhlanga, our researcher, who undertook on our behalf extensive research of key peer and industrialised nations' NSIs and provided valuable input into our findings and recommendations.

Finally, I record my sincerest appreciation to my colleagues and Ministerial Committee members who invested so much of their time, energy, passion, empathy, wisdom and patience in developing this report -

Prof. Anastassios Pouris;
Prof. Aris Sitas;
Prof. Brian Figaji;
Mr Lumkile Mondi;
Ms Marjorie Pyoos;
Mr Mpho Madisha;
Prof. Puleng LenkaBula;
Prof. Thenjiwe Meyiwa, and
Dr Sibusiso Manzini.

Our diverse and experienced team bring commendable experience and insights from across the higher education, science and innovation system including civil society.

So, with our work completed, we are honoured to hand over this report to Minister Nzimande for his consideration and action.

Prof. Ihron Rensburg

Chairperson: Ministerial Committee on the Review of the Higher Education, Science, Technology, Innovation and Information Landscape

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Acronyms and abbreviations

4IR	Fourth Industrial Revolution
ACCESS	Applied Centre for Climate and Earth System Sciences
ACSA	Airports Company of South Africa Limited
ADP	Advanced digital production
AIDS	Acquired immunodeficiency syndrome
APTs	Advanced Production Technologies
ARC	Agricultural Research Council
ASGISA	Accelerated Shared Growth Initiative of South Africa
ASSAf	Academy of Sciences of South Africa
ATS	Antarctic Treaty System
AU	African Union
BCLME	Benguela Current Large Marine Ecosystem
BBBEE	Broad-Based Black Economic Empowerment
BERD	Business Expenditure on Research and Development
BNFL	British Nuclear Fuels
PBMR	Pebble Bed Modular Reactor
BRICS	Brazil, Russia, India, China and South Africa
CAIR	Centre for Artificial Intelligence Research
CAPRISA	Centre of Excellence in HIV Prevention
CBTBR	Centre of Excellence for Biomedical Tuberculosis Research
CEF	Central Energy Fund
CEO	Chief Executive Officer
CERN	European Organization for Nuclear Research
CeSTII	Centre for Science, Technology and Innovation Indicators
CET	Community Education and Training
CGS	Council for Geosciences
CHPC	Centre for High Performance Computing
CIPC	Companies and Intellectual Property Commission

COMRO	Chamber of Mines Research Organisation
COMSA	Chamber of Mines South Africa
CREST	Centre for Research on Evaluation, Science and Technology
CSI	Corporate social investment
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated solar plants
CUSS	Carbon capture, utilisation and storage
CUT	Central University of Technology
DAAD	German Academic Exchange Service
DAFF	Department of Agriculture, Forestry and Fisheries
DCDT	Department of Communications and Digital Technologies
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry and Fisheries
DG	Distributed generation
DHET	Department of Higher Education and Training
DIR	Digital Information Revolution
DIRISA	Data Intensive Research Initiative of South Africa
DNA	Deoxyribonucleic acid
DoD	Department of Defences
DoT	Department of Tourism
DSD	Department of Social Development
DSI	Department of Science and Innovation
DST	Department of Science and Technology (former)
dti	Department of Trade and Industry (former)
DTIC	Department of Trade, Industry and Competition
DWS	Department of Water and Sanitation
EEZ	Exclusive economic zone
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
EG	Embedded generation
EHR	Electronic Health Record
EIB	European Investment Bank

EIEI	Economic Sectors, Investment, Employment and Infrastructure
EIEID	Economic Sectors, Investment, Employment and Infrastructure Development
EPPEI	Power Plant Engineering Institute
ESSRP	Earth Systems Science Research Programme
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FPB	Film and Publication Board
FHG	Fraunhofer-Gesellschaft (Fraunhofer Society)
FPL	Food poverty line
FTE	Full-time equivalent
GDP	Gross domestic product
GEAR	Growth, Employment and Redistribution
GEM	Global Entrepreneurship Monitor
GEOSS	Global Earth Observation System of Systems
GERD	Gross Expenditure on Research and Development
GHG	Greenhouse gas
GFI	Global Financial Integrity
GM	General Motors
HDI	Human Development Index
HEI	Higher education institutions
HELE	High energy low emission
HEMIS	Higher Education Management Information Systems
HESI	Health Education Systems Incorporated
HESTI	Higher Education, Science, Technology and Innovation
HESTILL	Higher Education Science, Technology and Innovation Infrastructure Landscape
HET	Higher Education and Training
HIV	Human immunodeficiency virus
HPE	Hydro Power Equipment
HSRC	Human Sciences Research Council
HySA	Hydrogen South Africa

ICASA	Independent Communications Authority of South Africa
ICT	Information and communications technology
IDC	Industrial Development Corporation
IDM	Institute of Infectious Diseases and Molecular Medicine
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme
IIP	Industry Innovation Partnership
IKS	Indigenous knowledge systems
IMR	(Norwegian) Institute of Marine Research
IMT	Institute for Maritime Technology
IOISA	International Ocean Institute of South Africa
IOR	Indian Ocean Rim
IP	Internet protocol *or* Intellectual property
IPAP	Industrial Policy Action Plan
IPPs	Independent Power Producers
IRP	Integrated Resource Plan
IUCN	International Union for Conservation of Nature
JSE	Johannesburg Stock Exchange
KAT	Karoo Array Telescope
KRISP	UKZN Research and Innovation Sequencing Platform
KZN	KwaZulu-Natal
LHC	Large Hadron Collider
LTMS	Long Term Mitigation Scenarios
M&E	Monitoring and evaluation
MARS	Marine and Antarctic Research Strategy
MCEP	Manufacturing Competitive Enhancement Programme
MIDP	Motor Industrial Development Programme
Mintek	Council for Minerals Technology
MNEs	Multinational enterprises
MOTIP	Management of technology, innovation and people
MRC	Medical Research Council

MTSF	Medium Term Strategic Framework
MW	Megawatt
NACI	National Advisory Council on Innovation
NAPHISA	National Public Health Institute of South Africa
NCPC	National Cleaner Production Centre
NDoH	National Department of Health
NDP	National Development Plan
NECSA	South African Nuclear Energy Corporation
NEET	Not in Education, Employment or Training
NEMISA	National Electronic Media Institute of South Africa
NEMO	National Environmental Management of the Ocean
NFF	New Funding Framework
NFRI	National Foundation for Research and Innovation
NGO	Non-governmental organisation
NHI	National Health Insurance
NHLS	National Health Laboratory Services
NHRC	National Health Research Committee
NICD	National Institute for Communicable Diseases
NICIS	National Integrated Cyber-Infrastructure System
NIHSS	National Institute for the Humanities and Social Sciences
NIOH	National Institute for Occupational Health
NIPMO	National Intellectual Property Management Office
NMISA	National Metrology Institute of South Africa
NMU	Nelson Mandela University
NNR	National Nuclear Regulator
NPOs	Not-for-profit organisations
NRCS	National Regulator for Compulsory Specifications
NRDS	National Research and Development Strategy
NRF	National Research Foundation
NSF	National Skills Fund
NSFAS	National Student Financial Aid Scheme

NSI	National System of Innovation
NSTF	National Science and Technology Forum
NWMS	National Waste Management Strategy
NWU	North-West University
OECD	Organisation for Economic Co-operation and Development
OHSC	Office of Health Standards Compliance
ORI	Oceanographic Research Institute
PASA	Petroleum Agency of South Africa
PBMR	Pebble Bed Modular Reactor
PCT	Patent Cooperation Treaty
PFMA	Public Finance Management Act
PhD	Doctor of Philosophy
PMFA	Primary Malignant Fibrous Histiocytoma
PRASA	Passenger Rail Agency of South Africa
PRI	Public Research Institute
PSEC	Presidential State-Owned Enterprises Council
PSET	Post-School Education and Training
PV	Photo-voltaic
R&D	Research and development
RDI	Research, development and innovation
RDP	Reconstruction and Development Programme
REF	Research Excellence Framework
RET	Radical economic transformation
RU	Rhodes University
SA	South Africa
SAAO	South African Astronomical Observatory
SABC	South African Broadcasting Corporation SOC Limited
SABS	South African Bureau of Standards
SAC	Satellite Applications Centre
SACEMA	Centre of Excellence in Epidemiological Modelling and Analysis
SADC	Southern African Development Community

SAEON	South African Environmental Observation Network
SAEOSS	South African Earth Observation System of Systems
SAIAB	NRF/South African Institute for Aquatic Biodiversity
SAMRC	South African Medical Research Council
SAMSA	South African Maritime Safety Authority
SANAP	South African National Antarctic Programme
SANAS	South African National Accreditation System
SANBI	South African National Biodiversity Institute
SANEDI	South African National Energy Development Institute
SANRAL	South African National Roads Agency
SANReN	South African Research Network
SANSA	South African National Space Agency
SAPO	South African Post Office
SARChI	South African Research Chairs Initiative
SARIR	South African Research Infrastructures Roadmap
SARVA	South African Risk and Vulnerability Atlas
SARS	South African Revenue Service
SASSCAL	Southern African Science Service Centre for Climate and Land Management
SAVP	South African Vaccine Producers
SAWS	South African Weather Service
SDGs	Sustainable Development Goals
SEDA	Small Enterprises Development Agency
SET	Science, engineering and technology
SETAs	Sector education and training authorities
SI	Specialisation index
SIF	Sector Innovation Funds
SITA	State Information Technology Agency
SKA	Square Kilometre Array
SMM	Strategic Management Model
SMME	Small, medium and micro enterprise
SOE	State-owned enterprise

SPII	Support Programme for Industrial Innovation
SSEG	Small-scale embedded generation
STAs	Scientific and technological activities
StatsSA	Statistics South Africa
STEM	Science, technology, engineering, and mathematics
STI	Science, technology and innovation
STI-WP	Science, Technology and Innovation White Paper
STIIL	Science, Technology and Innovation Institutional Landscape
SU	Stellenbosch University
TB	Tuberculosis
THRIP	Technology and Human Resources for Industry Programme
TIA	Technology Innovation Agency
ToR	Terms of reference
TUT	Tshwane University of Technology
TVET	Technical and Vocational Education and Training
UCT	University of Cape Town
UFS	University of the Free State
UJ	University of Johannesburg
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UL	University of Limpopo
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
Unisa	University of South Africa
UP	University of Pretoria
US	United States

USA	United States of America
USAASA	Universal Service and Access Agency of South Africa
USAf	Universities South Africa
USPTO	United States Patent and Trademark Office
UV	University of Venda
UWC	University of the Western Cape
VMS	Vessel Monitoring System
WACS	West Africa Cable System
WHO	World Health Organization
WHRI	Wits Reproductive Health and HIV Institute
WIPO	World Intellectual Property Organisation
Wits	University of the Witwatersrand
WP	White Paper
WRC	Water Research Commission
WWF	World Wildlife Fund

Executive summary

I. Background

The National Development Plan (NDP) outlines a compelling vision of the role of science, technology and innovation in South Africa's development[1]. The NDP recognises the importance of science and its applications in driving innovation that catalyses economic growth that is so critical for addressing the pervasive social problems of the country. To enhance the capacity of the science, technology and innovation system to support the country's development objectives, the NDP proposes a number of improvements to the system. Among other recommendations, the NDP calls for the country to:

- Sharpen its innovation edge;
- Increase investments in research and development;
- Secure a far more efficient use of existing resources;
- Catalyse more nimble institutions that facilitate innovation; and,
- Enhance cooperation between the public and private sectors[2].

Furthermore, recognising their central role in the achievement of innovation, the NDP calls for urgent coordination and collaboration between universities, science councils, other government structures, non-governmental organisations and the private sector[3].

The collective set of functioning institutions, organisations and policies that interact constructively to bring about the shared social and economic goals referred to above, is known as the National System of Innovation (NSI)[4]. The NSI has been the conceptual bedrock for South Africa's science, technology and innovation (STI) policy since 1996. This approach is consistent with the prevailing policy perspectives and pathways of industrialised and industrialising economies across the planet[5]. The 2019 White Paper on Science, Technology and Innovation, which draws its objectives from and is fully aligned with the NDP, endorses the continued adoption of the NSI as a framing construct for STI policy in the country[6].

Since 1996 some notable improvements have been realised in the NSI. The NSI has shifted towards a broader social mandate and away from supporting the apartheid-era STI agendas that were designed to shore up that maligned system. There has been an increase in the participation of women and black people in the knowledge enterprise. The country's knowledge output has risen appreciably, particularly in the past ten years. New organisations have been established, and various institutional reconfigurations implemented. In response to a succession of policies and plans, these actions sought to strengthen the capacity of the NSI. Notwithstanding these improvements, on both the input and output sides, the 2019

[1] RSA. 2012. National Planning Commission: National Development Plan Vision 2030. Pretoria: Government Printing Works.
[2] Ibid
[3] Ibid
[4] Department of Arts, Culture, Science and Technology (DACST). 1996. White paper on science and technology: Preparing for the 21st century. Pretoria: DACST.
[5] OECD. 1991. National Innovation Systems. http://www.oecd.org/science/inno/2101733.pdf.
[6] DST. 2019. White Paper on Science, Technology and Innovation. Pretoria.

White Paper on STI addresses long-standing shortcomings that continue to limit the capacity of the system[7]. With less than ten years of the term of the NDP Vision 2030 remaining, there is a need to address the outstanding impediments to the attainment of the objectives contained therein.

The most recent and significant organisational change in NSI governance is the consolidation of the higher education and training and science and innovation departments under the common political oversight of the new Minister of Higher Education, Science and Technology. This integration provides an opportunity to strengthen linkages within the NSI that can intensify collaboration and coherence. Importantly, it is the collective of higher education institutions (public and private), science councils and other government STI entities, non-governmental organisations (NGOs) and the private sector, that constitute the NSI. The emergence of the new Ministry facilitates a perspective on the NSI that focuses and mobilises the separate and complementary roles of Higher Education, Science, Technology and Innovation (HESTI) institutions in knowledge generation and technological innovation. This gives rise to a fresh construct, namely the HESTI institutional landscape, or HESTIIL, to apply in exploring and intensifying coherence and coordination. Such efforts can and must significantly enhance the social and economic impact of the NSI.

A HESTIIL perspective is highly significant in that it incorporates a large swathe of STI institutions that contribute to the functioning of the NSI, including the public, private and the non-profit sectors. The HESTIIL in its entirety, as a subject of this review, constitutes a substantial contextual representation of the NSI. Therefore, for all practical purposes, the HESTIIL is an apt generalization of the entire NSI, unless the context dictates otherwise.

II. Purpose of the HESTIIL Review

This review was commendably commissioned right at the outset by the new Minister of Higher Education, Science and Technology. It followed directly upon the combination of the higher education and science and innovation portfolios in one ministry. Drawing from the Terms of Reference outlined in the full Panel Report, the purpose of this review is to investigate the extent to which the HESTIIL is able to optimally assist in the achievement of the NDP priorities and to respond to the country's socio-economic needs. The remit of the Review Panel includes identifying any gaps in the existing institutional landscape. Furthermore, the Minister commissioned the Review Panel to propose a model for higher education, science, technology and innovation (HESTI) institutions that could enhance the promotion of coherent, integrated and optimised mandates. In each case these should be designed within common policy frameworks that can be applied across all the significant components of the NSI.

Taking into consideration the 2019 White Paper on Science, Technology and Innovation (the STI White Paper) as well as the White Paper on Post-School Education and Training and other relevant policies, the review includes:

[7] Ibid.

- The development of a description and graphic depiction of the current higher education, science, technology and innovation landscape.
- An analysis of the capacity of existing institutions to support post-school education and training and to undertake strategic research to produce knowledge spanning the social and natural sciences and the humanities.
- An analysis of the HESTI institutions to establish programmatic focus, intensity of activity, concentration or dispersion of activity, and impact on the realisation of policy outcomes; and,
- An analysis of the strengths, weaknesses, opportunities and threats across the NSI.

Ultimately, in the terms outlined above, the HESTIIL Review Panel was required to advise the Minister of Higher Education, Science and Technology on:

- The relevance of the current institutional landscape to current contexts and anticipated future needs.
- Areas of research whose activity and output do not match the scope and level of the other dedicated institutions; and,
- The contribution and overall effectiveness of existing institutions in bridging the transition from basic to applied research and commercialisation.

III. The Review Context

In the remaining term of the country's first National Development Plan 2030 (NDP 2030), a number of contextual factors frame and shape the future of the NSI. Significant and sustained economic growth has consistently eluded the country in recent years and the trend regrettably looks set to continue and even intensify in the wake of the COVID-19 global pandemic. The enduring high levels of unemployment, poverty and inequality are expected to continue to disfigure the socio-economic landscape and compel government to commit to even higher levels of social spending. The capacity of the country to navigate the threats and opportunities presented by the Fourth Industrial Revolution (4IR) will be sorely tested amid growing concerns about the capacity of the state, particularly the many struggling state-owned enterprises. There is therefore an urgent need to restore public confidence in state institutions through effective leadership and ethical management of public resources.

The NSI has been the subject of several review studies in the past that addressed and made recommendations on a number of significant matters, including:[8,9,10,11]

[8] OECD. 2007. OECD Reviews of National Policy: South Africa. https://dx.doi.org/10.1787/9789264038240-en DST. 2017. Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape. Pretoria.

[9] DST. 2012. Department of Science and Technology Ministerial Review Committee on the Science, Technology and Innovation Landscape in South Africa. Pretoria.

[10] DST. 2017. Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape. Pretoria.

[11] NACI. 2020. A Review of the National Research and Development Strategy and (NRDS) and Ten-Year Innovation Plan (TYIP). NACI: Pretoria.

- Financing of the system and its expansion.
- Effective advisory support and the role of NACI.
- System governance and the regulatory environment.
- Mandates and the knowledge infrastructure.
- Policy coordination and strategic management.
- Human capacity development and transformation; and,
- Monitoring and evaluation.

Some of the recommendations from these past studies were acted upon; others were only partially implemented, and many were, disappointingly, completely eschewed for varying reasons. The Review Panel understands that there are sometimes cogent reasons for not implementing the recommendations. Nevertheless, the history of random responses to the recommendations of review studies has meant that many of the historical and prevailing weaknesses in the country's HESTIIL endure, and many opportunities to transform the system are not seized upon.

IV. Approach and Methodology

The extent and complexity of the mandate given to the Review Panel called for a range of methodological approaches that enabled the Review Panel to address the key components of the study. In broad terms, these methodological approaches included:

- ***Situational analyses*** *– applying a correlative and evolutionary approach to the SWOT analysis to establish the foundations, pillars and differentiated advantages of the NSI, as well as opportunities to intensify and accelerate it, taking into account the demand for its enhanced and accelerated social and economic impact.*
- ***Capacity analysis*** *– an in-depth examination of the HESTI institutional landscape to establish the scope, scale and depth of the NSI, across various mandates and disciplines, and its absorptive capacity for urgent and focused expansion.*
- ***Institutional landscape mapping*** *– employing heatmaps and other graphics, as well as other analytical tools, to track and identify interconnectivity through resource flows within the NSI and areas that require urgent remediation.*
- ***Case studies*** *– critical analyses of a range of historical NSI initiatives to excavate and elevate NSI project/programme successes and failures, in order to bring the lessons from these to bear on the review, and to provide for HESTIIL system learning.*
- ***In-depth stakeholder engagements*** *– to source critical insights into high-performing/high-performance NSI actors and to identify for focused attention outliers and institutions/actors requiring realignment and renewal.*
- ***International benchmarking studies*** *– to benchmark SA's NSI against leading industrial economies (South Korea, Japan, Singapore and OECD countries) and comparable industrialising countries or contexts in the developing world (Brazil, China and India); and*
- ***An extensive consultative process with critical state, business and industry and civil society actors within the NSI*** *– these engagements provided platforms to source critical and live insights into the 'as is' NSI, to learn about actors' visions for the desired future NSI, and to test our initial findings and provisional recommendations.*

The above outline only maps out the broad approaches and their intended outputs. Within each of the seven methodological approaches, the review process involved a blend of data collection and analyses approaches which were implemented to elicit, deconstruct and

synthesise the breadth, depth and quality of data that reflect the complexity of the HESTIIL as a major component of the NSI.

The Review Panel wishes to bring to the attention of the reader the following considerations as a guide to be kept in mind in processing the key issues, findings and recommendations presented in this report:

- The review is premised on the need to address incoherence and fragmentation that plagues the NSI. This weakness is a preceding reality that is part of the rationale for instituting the review, in accordance with the Terms of Reference.
- The Review Panel, operating with the understanding that it is working independently, rigorously applied its collective expertise to all the data acquired through the review process outlined in the foregoing section. All the elements of the report, particularly the recommendations, are aimed at providing the best possible responses to the NSI weakness outlined above.
- As discussed in the body of the report, the NSI is the ultimate unit of analysis of the review and the report. Where the findings point to weaknesses in the system, these do not necessarily apply to the DSI or DHET. A whole system perspective should be kept in mind when reading the report, unless the context suggests otherwise.

V. Summary of Key Issues and Findings

The overriding finding of the Review Panel is that the HESTI institutional landscape is not adequately capacitated to support the achievement of the country's objectives as outlined in the NDP. As a consequence of the gaps and shortcomings of the HESTIIL, the capacity of the NSI to drive knowledge-based economic growth (and ipso facto inclusive social development and shared prosperity) through to industrial development is severely constrained. The Review Panel is of the view that unless urgent and decisive action is taken, there is a real danger that the gains that have been made since 1994 in developing the country's NSI could slide into regression, leading to incalculable social and economic costs to the people of South Africa.

The following is a summary of the key issues and findings that emerged from the HESTIIL Review:

1. Although official documents - from the Constitution[12] to the NDP and other NSI organisational policies and plans - are replete with references to values, these are generally eschewed in implementation plans and management practice. Performance plans, annual reports, human resource management and development protocols, in general, do not to leverage the country's sound value system for people and organisational development.

2. With a few notable exceptions, the NSI is poorly interconnected and chronically siloed. This gives rise to incoherent and suboptimal programmes. Instead of cooperation, unhealthy competition is rife, particularly within the public sector. Opportunities for developing programmatic synergies are not seized upon as organisations, and units

[12] RSA. 1996. Constitution of the Republic of South Africa, Chapter 3.

within them, chase after scarce resources. The existing incentive schemes do not adequately promote collaboration and are often implicated in polarising the system. Crucially, the current HESTI policies and incentive schemes have not promoted sufficient private sector participation in local innovation.

3. There is no coherent nor comprehensive system-level agenda and priority setting. With notable exceptions, there has been very little coordination and integration of strategy and planning even between DSI and DHET, let alone across the whole of government. As a rule, government departments work in isolation of each other, despite specific provisions in the Constitution that demand cooperation[13]. Furthermore, the lack of an apex oversight authority disables the system from deriving the crucial benefits of an elevated steering mechanism that can foster cooperation within government and across other sectors within the NSI. In order for the country to fully realise the social and economic benefits envisioned in the NDP that should derive from STI, this situation must be remedied, and urgently so.

4. The apex and system-level advisory mechanism – the National Advisory Council on Innovation (NACI) - is significantly suboptimal in terms of its membership, capacity, authority and influence. Even when it conducts important studies that bear system-wide implications, its advisory role is limited to the entities within the DSI portfolio, thereby significantly confining its desired impact.

5. The role of business and industry in local innovation is waning quite dramatically, and their participation and investments in domestic research, technology transfer and industrialisation are, troublingly, in a long-run state of decline[14]. There are strong indications that investments in these activities are effectively off-shored to science entities and universities in industrialised nations. This trend has devastating consequences for the development of South Africa's NSI, and for reindustrialisation and the creation of new industries.

6. HESTIIL is situated within and is inextricably linked with the country's political economy. The situational analysis revealed that key forces and tendencies that play out and often polarise the South African political economy have direct implications for HESTIIL. These include phenomena such as rent seeking, an excessive profit motive, adverse interorganisational network behaviours and undesirable financial outflows. These practices – some of which have been adopted by SOEs and other public entities - are inimical to innovation and a people-centric policy regiment. Financial outflows, both legal and illicit, constrain private sector investment in research and development and thus undermine the capacity of the economy to grow.

7. The State-Owned Enterprises (SOEs) have, troublingly, since the end of apartheid, forfeited their role as key actors within the NSI. Their participation in R&D has fallen precipitously across all key measures. This underscores the diminishing role of this

[13] RSA. 1996. Constitution of the Republic of South Africa, Chapter 3, Section 41.
[14] CeSTII. 2019. South African National Survey of Research and Experimental Development: Statistical Report: 2017/18. HSRC: Pretoria.

sector in the development of a knowledge economy[15]. The ambitions of the STI White Paper and the forthcoming Decadal Plan for STI are unlikely to be fully realised without a revival of the SOEs as key players in the knowledge enterprise. The extensive geographical and functional footprint of the SOEs in the economy is a necessary asset for extending the participation (and benefits) of the marginalised actors and communities in grassroots science and innovation.

8. The NSI conceptual framework has succeeded in organising policymaking, and the monitoring and evaluation of knowledge-based activity in the country. It has also fallen short in some important respects, notably in accommodating poor and marginalised sections of the population. South Africa has made great strides in human development. These strides are however tarnished by the country's extremely high level of inequality[16]. Importantly, the conceptualisation of inclusive innovation in the STI White Paper should rather be built upon the foundation of a rigorous analysis of the issues that motivate for inclusivity. In this manner the measures that have been identified for bringing about inclusivity in the 2019 White Paper can be reconceptualised in order to achieve their intended goals and objectives.

9. There is no coherent system of reporting across science entities, universities and SOEs. This makes it impossible to track and monitor system level information on a real-time basis. Furthermore, the lack of measures to determine social and economic impact in the current innovation metrics should be remedied to enable the accurate tracking of progress. Linkages between individual institutional mandates and annual performance plans of many entities on one hand, and their institutional roles and mandates within the NSI on the other, are weak to non-existent, and these should be remediated.

10. The HESTIIL Review Panel identified several institutional weaknesses both within and between some of the key entities. A set of NSI institutions are either too small, have little impact, are poorly funded or their location within the NSI is misplaced. To illustrate, the vitally important Technology Innovation Agency (TIA) is short on leadership stature and financial capacity and has largely failed to pursue and achieve the ambitious goal of facilitating and commercialising hundreds of new ventures in advanced technologies.

11. There is considerable investment and research (over 7% of gross expenditure on R&D) in the field of environmental sciences with multiple stakeholders across a range of industry sectors, government departments, research agencies, universities and non-profit research organisations. However, the institutional capacity analysis revealed that there is no environment, marine and earth sciences council, despite the vibrant research activity and investment in researcher training. The extensive but fragmented research activity that currently defines this sector is sub-optimal and is out of sync

[15] Statistics SA. 2019. South African National Survey of Research and Experimental Development: Statistical Report 2018/18. Pretoria.
[16] UNDP. 2019. Inequalities in Human Development in the 21st Century: Briefing note for countries on the 2019 Human Development Report – South Africa

with the global significance of South Africa's biodiversity and environmental conservation programmes and this should be remediated.

12. There are strong indications that some government departments do not provide appropriate strategic guidance and oversight to their science councils and other research institutions. These science councils and other research entities were created by their founding departments of state to serve their respective priorities and stakeholders. In some cases, over time, the relationships between the parent departments and their research institutions have weakened or completely collapsed.

The implications of the above issues and findings are far-reaching. Already, there are strong indications in the available data sets that South Africa's negative technology balance of payments is persistently wide[17]. The spectre of de-industrialisation is no longer a threat but a present and growing economic reality[18]. South Africa remains enmeshed in a decades-long middle-income trap with a negative prognosis[19]. At this rate, the NDP objectives of rolling back unemployment, poverty and inequality will regrettably not be achieved. The social and humanitarian ramifications of such a forecast catastrophic failure are too appalling to countenance.

VI. An Urgent Need to Pivot the System

The above compendium of gaps and shortcomings suggests a need to pivot the HESTIIL on an urgent basis. Both the NDP and the STI White Paper call for addressing the fragmentation of the NSI at the system and programme levels. Time-series analyses of various NSI indicators suggest that the current crisis has been long in the making, particularly so in the last decade[20].

On the policy front, the inducements that came with the 1996 White Paper on Science and Technology, and followed up by the National Research and Development Strategy, have run their course, and these have taken the NSI as far as they could. The institutional and governance mechanisms that were proposed by these policies have either been implemented, postponed or ignored, as the case may be[21]. These include, among several others, the establishment of organisations such as TIA and the implementation of the Strategic Management Model[22]. The science and technology missions that emerged from those policies have been implemented, and some have since come to an end. Recent systemic reviews paint a bleak picture of some of these efforts[23].

[17] NACI. 2020. A Review of the National Research and Development Strategy and (NRDS) and Ten-Year Innovation Plan (TYIP). NACI: Pretoria.
[18] Andreoni, A., & Tregenna, F. (2018). Stuck in the Middle: Premature Deindustrialisation and Industrial Policy. CCRED Working Paper 11/2018.
[19] Felipe, J., Abdon, A., & Kumar, U. 2012. Tracking the Middle-Income Trap: What is it, who is in it, and why?. Working Paper No 715, Levy Economics Institute of Bard College, Annandale-on-Hudson. New York.
[20] Statistics SA. 2019. South African National Survey of Research and Experimental Development: Statistical Report 2018/18. Pretoria.
[21] DST. 2017. Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape. Pretoria.
[22] NACI. 2020. A Review of the National Research and Development Strategy and (NRDS) and Ten-Year Innovation Plan (TYIP). NACI: Pretoria.
[23] ibid.

There are further signs that are indicative of the onset of policy fatigue in the HESTIIL. The push for increased investments in higher education and research and development to support the emergence and transformation of the democratic state appears to have run out of steam. The Gross Expenditure on Research and Development (GERD) has plateaued despite increased contributions from government[24]. The existing inducements for increased expenditure by the private sector are met, at best, with only a lukewarm response[25]. The fervent call for increased support for higher education that reached a crescendo in the #FeesMustFall campaign has been subdued by the cold reality of fiscal constraints in the context of flat, and more recently, negative economic growth. In the aftermath of the COVID-19 pandemic, and the economic havoc it is leaving in its wake, the prospects of achieving the NDP target of raising the GERD to 1.5% of gross domestic expenditure (GDP) are decidedly bleak.

Even where relative success has been recorded in research and development[26], new searching questions have emerged that put a damper on these achievements. The phenomenal growth in the publication output in the past ten years has given rise to questions about the quality of some of the outputs - and more significantly for society and the economy - the dearth of a concomitant rise in the translation of the knowledge outputs into innovations that have a social or economic impact. The innovation chasm that has been the bane of the NSI since it was identified in the National Research and Development Strategy remains unresolved[27]. Moreover, as the country works hard to catch up with the leading industrial economies, the gap seems to grow wider as the competitors continue to set and achieve even more stretch benchmarks.

All the above signs suggest that the NSI lacks vibrancy and momentum. If it is allowed to continue on this trajectory, it will fail to bring about genuine inclusive innovation and thus undermine the NDP goals. Owing to the range and multiplicity of the weaknesses, the Review Panel is of the view that the system will not respond optimally to piecemeal interventions. There is an urgent need for a comprehensive pivoting of the system. Incremental measures that amount to the extension of the status quo, will simply not yield the desired results. The case for an urgent system pivoting is illustrated in the accompanying diagram.

[24] Statistics SA. 2019. South African National Survey of Research and Experimental Development: Statistical Report 2018/18. Pretoria.
[25] Ibid
[26] DHET. 2019. Report on the Evaluation of the 2017 Universities' Research Output. Pretoria
[27] Government of South Africa. 2002. *South Africa's National Research and Development Strategy*. Pretoria: Government of South Africa.

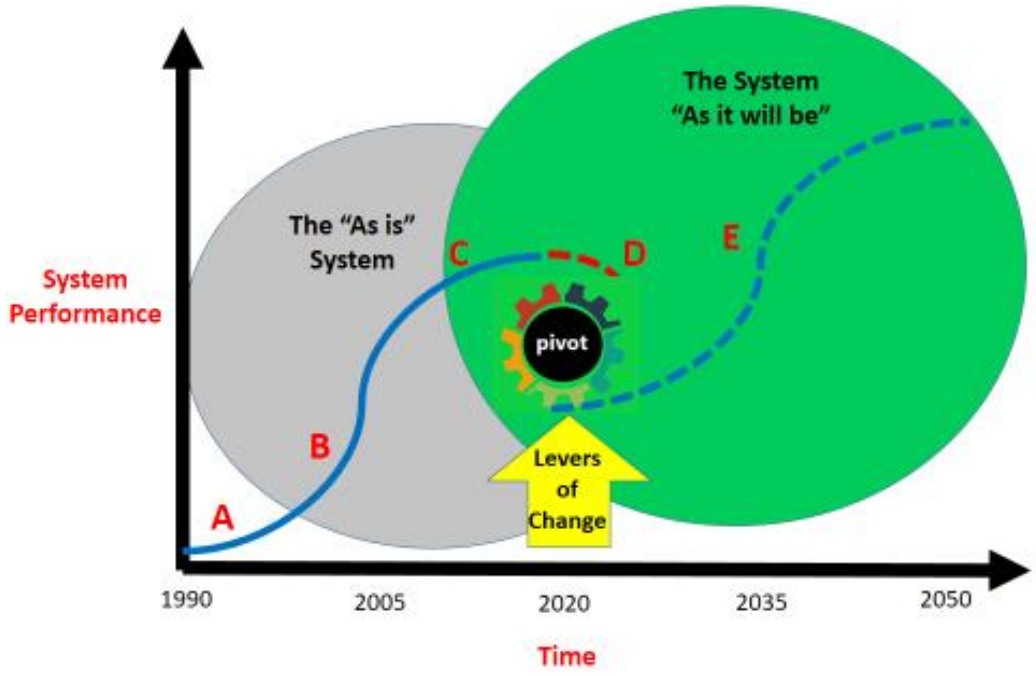

Figure 1: Pivot Diagram – Applying Levers of Change to tilt the current NSI to an Idealised State

As shown in the accompanying figure, the NSI has undergone some changes in the past thirty years. Over this period the system has, in broad terms, responded to the changing policy regime as follows:

A – The system as inherited from the apartheid state, stuttering owing largely to international isolation.
B - Following policy inducements in 1996 and 2002, the NSI was in a buoyant state, and performing well.
C – After 2010, the system is showing clear signs of stagnation and decline (as discussed above).
D – If a "business-as-usual" approach is taken, the system will slide into regression.
E – If the proposed set of measures to pivot the system are taken, the NSI will be translated into a new performance trajectory and thus grow and flourish.

In this context, pivoting is a process by which a system that is in a state of decline is transformed and tilted onto a higher and more sustainable growth path through the application of a set of inducements.

VII. The Levers of Change

To address the gaps and shortcomings that emerged from the above issues and findings, the HESTIIL Review Panel formulated a set of recommendations that are designed to pivot the system and elevate it onto a higher performance trajectory. The recommendations are organised around a set of five levers of change for the NSI. These are: Values, Governance, Resourcing, Capabilities, and Coherence.

Before presenting the recommendations, we first outline the levers of change in order to unpack the multipronged and yet holistic process of targeted system pivoting.

Values are socially shared "conceptions of the desirable"[28]. Values provide a bedrock of principles to guide management practice particularly during uncertain times. When the Review Panel held a consultative meeting with the leaders of the HESTI institutions, a strong call came out for the strengthening of values in leadership. At a time when public confidence in the capacity of the state is under intense examination, it is paramount to strengthen the ethical basis of the NSI by ensuring that there is alignment across the system on what it means to be a public servant or institution, as well as drive home the imperative to honour the country's Constitution.

Governance incorporates all aspects that concern political oversight, strategic management and the advisory support for the NSI. Many of the issues outlined above point to weaknesses in coordination across government and a decline in effective cooperation across all sectors of the economy. Governance therefore serves as an important lever of change for providing an organising framework for interventions that aim to improve steering and oversight of the NSI, and to combat fragmentation at a system level.

Resources encapsulates recommended actions for the optimisation of financial and other resources available to the NSI. The quest to grow investments in research and development has been a challenging one, even during the best of times, as the stubborn historical GERD trend affirms[29]. The increased fiscal pressure that is ever-present places a greater premium on the need for smart investments and efficiency in the distribution and expenditure of scarce resources.

Capabilities refers to all the necessary capabilities that the institutional landscape requires to effectively manage the process of converting knowledge and know-how into commercially viable products and services. Apart from the standard innovation capabilities that are often measured as inputs in innovation surveys, there are complementary capabilities that are important[30]. The recommendations address a range of institutional capabilities essential for innovation, including the complementary capabilities.

Coherence encompasses the aspects that relate to forging and maintaining fruitful interactions and partnerships between various actors in the HESTIIL to address programme fragmentation. Our international benchmarking exercise has affirmed that successful innovation systems are characterised by a high level of coherence derived from closer collaboration and effective networking.

[28] Rokeach, M. 1979. Understanding Human Values: Individual and Societal. The Free Press: New York.
[29] Statistics SA. 2019. South African National Survey of Research and Experimental Development: Statistical Report 2018/18. Pretoria.
[30] Cirera, X. & Maloney, W. F. 2017. The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up. Washington DC: World Bank. https://openknowledge.worldbank.org/handle/10986/28341 License: CC BY 3.0 IGO.

These five levers of change are used below to organise the recommendations proposed by the panel. In practice, all five levers work together in mutually reinforcing ways. When they work together effectively, a virtuous circle is created. The intended pivoting of the system, to address the identified gaps and weaknesses, is likely to succeed if all the levers of change are engaged given that they are systemically linked. In this consideration, it is therefore more appropriate to conceptualise the levers of change not as separate leverage points, but as a holistic and targeted system pivoting mechanism. This requirement applies even when the interventions are scheduled for different times and locations within the institutional landscape, as advocated by the HESTIIL Review Panel.

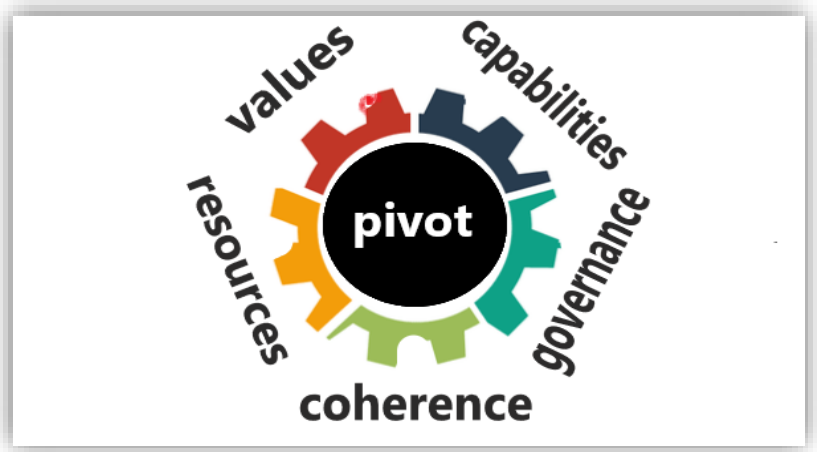

Figure 2: An Illustration of the Levers of Change as a Holistic Pivoting Mechanism for the NSI

VIII. Recommendations

The recommendations below outline the proposed interventions that are designed to pivot the NSI and tilt it towards a higher growth trajectory and performance level. The recommendations derive from a rigorous process of data analysis across all the components of the review. They are organised around the five Levers of Change outlined above.

Values

1. Future HESTI policies, plans and programmes should be grounded in the country's value system, in accordance with the growing voice of the STI community and the prevailing concerns of the broader society. The country's values base and the changing international dynamics offer opportunities for a positive discourse in this regard. The African philosophy of *Ubuntu* may provide a common foundation for rebuilding a values-based HESTIIL and for restoring public trust in state institutions and programmes, while affirming indigenous knowledge systems and their role in nation-building among other practical applications.

2. There is a need to incorporate values that are aligned with entrepreneurship within the country's innovation discourse to support the overall thrust of STI policies, particularly in relation to inclusive innovation. The multimodal promotion of entrepreneurial values, among all sectors of the population, will help to create an

enabling environment for technology-based enterprise development initiatives, including training. Japan offers a good example of an industrial economy that emerged on the strength of its traditional value system and the incorporation of modern demands.

Governance

3. There is a need to pivot the current HESTIIL towards increased coherence and coordination, while combating fragmentation and unhealthy competition. In line with the STI White Paper, transitioning the system to the idealised landscape involves, initially, establishing a four-tier agenda and priority setting, steering, implementation and monitoring framework. The components of the governance framework include the establishment of the Presidential Advisory Council on Science and Innovation, whose primary role is to set the agenda for the NSI through, for example, considering and approving four to five societal grand challenges or missions. The Presidential Advisory Council will be supported by an Inter-Ministerial Committee and an Inter-Departmental Committee of Directors-General. Additional details about the tilting of the HESTIIL to the idealised state are spelled out in the next section below.

4. A set of profound measures have to be undertaken to restore the vitally important role of business and industry in the local research, technological development and innovation enterprise. Such measures should include –

    a. Securing business and industries' effective and authoritative participation in the Presidential Advisory Council.
    b. Reviewing the existing business and industry research, innovation and technology transfer tax incentive scheme for a possible pivot to greater effectiveness and impact.
    c. Establishing national and regional platforms to forge collaborations between universities, science entities, business and industry; and,
    d. Establishing industry-based Masters, Doctoral and Post-Doctoral programmes to strengthen networks within HESTIIL, while ensuring quality problem-focussed research training.

5. A call is made to reimagine and reinvent NACI into a substantive, legitimate and competent national advisory body. In order to widen its influence, it is recommended that it should be located within the Presidency as the secretariat to the Presidential Advisory Council.

Resourcing

6. To revitalise the participation of the business sector in the NSI, consideration must be given to conducting a review of the existing business and industry research, innovation and technology transfer tax incentives (see also recommendation 4b above). Where these are found to be inadequate, the necessary improvements should be instituted, as informed by consultations with the business sector.

7. The problem of capital flight should be addressed using all the opportunities and means at the government's disposal. Measures should be considered to reverse the decline of the BERD, both in real terms and as a proportion of the GERD. Studies should be undertaken to explore the most appropriate mix of funding sources, taking into account the objectives for an increased GERD, the dynamics of the local economy and the lessons from other comparable international economies.

Capabilities

8. Trade policies should enable an increase in the technological and social capital for local firms. The Ministries responsible for Science and Innovation, and Trade, Industry and Competition should be centrally involved in trade negotiations, so that trade agreements can be leveraged to drive industrialisation and technology transfer, and nurture and catalyse indigenous firms.

9. Moreover, as evidenced in the deeply polarising stand-off between many OECD countries and China, note should be taken of the risks and opportunities that arise within the ever-evolving political economy of the global NSI. Appropriate science and knowledge diplomacy measures and actions, such as has been successfully achieved in the instance of the SKA programme, should be undertaken to support the elevation and deepening of the country's NSI.

10. In addition to instituting a programme of industry-based research studies, it is recommended that post-graduate studies and publications within engineering and its allied disciplines (such as computer, information and advanced digital sciences and technologies) should be urgently supported. Such action would pivot the skills base towards innovation supporting capabilities. Additionally, it is recommended that an Advanced Engineering and Digital Technologies Science Institute to catalyse this nascent industry be established. Such an action would not be dissimilar to the establishment of the National Institute for Humanities and Social Sciences.

11. There is a need for a reconceptualization of the NSI to better position it for addressing unemployment, poverty and inequality. This can be achieved, among other means, by a comprehensive articulation of inclusive innovation, and a delineation of the NSI to accommodate the voices and participation of the marginalised communities. Policy makers and practitioners should take every available opportunity to equip themselves with the necessary knowledge and skills required for tilting the NSI towards real inclusive innovation.

12. In order for the country to achieve the NDP outcomes, the country's research capacity must be scaled up considerably, with a purposeful prioritisation of research and full-time researcher growth in critical areas for the economy and society. In this respect, the call for studies on the appropriate interventions to squarely address hunger, malnutrition and poverty is reinforced. The proposed Research Development and Innovation missions can provide the necessary focus for capacity building in areas that address head-on the fundamental needs of the South African people.

Coherence

13. A centralised single National Foundation for Research and Innovation (NFRI) should be established by 2030 to bring under one umbrella the various entities in the innovation system value chain, from those performing basic research to technology transfer, innovation and commercialisation entities. This would create a seamless innovation funnel that ensures that there are no chasms that stifle industrialisation. It is recommended that the NFRI be created from a consolidation and clustering of existing agencies into councils/fields/clusters according to their key areas of focus, and placing them under one implementation agency that will facilitate the innovation activities within the clusters. In this regard, the pathway for the establishment of United Kingdom Research and Innovation (UKRI), and similar implementing agencies in other peer nations is instructive. Establishing the NFRI would constitute the fourth tier of the new national coordinating framework (see recommendation 3).

14. To address the poor coordination and lack of integrated planning between the DSI and DHET, an inter-departmental planning, coordinating and system steering mechanism must be established. Similar interventions can be considered in relation to other government departments that ought to be working closely in the interest of an integrated HESTIIL.

15. A call is made for the state to use its considerable procurement muscle to stimulate and deepen domestic technology transfer and industrial innovation by setting aside a percentage of the state procurement spend for promoting local innovation.

16. The cross-cutting stewardship and oversight mandate of the Department of Environment, Forestry and Fisheries is well recognised, however the research intensity in both the basic and applied fields in the environmental sciences warrants dedicated coordination by the DSI under a new environmental and climate change research council. It is envisaged that such a new research entity would fall under the umbrella of the proposed National Foundation for Research and Innovation as detailed in recommendation 13.

17. Innovation policies need to take into account the intricacies of the local political economy in order to navigate and leverage the polar tendencies that are prevalent within and across the private and public sectors. A failure to recognise and accommodate these driving forces within the country's political economy will undermine the achievement of inclusive innovation and a transformed economy. Conversations with the private sector should include identifying anchor points for a shared worldview and the development of a social compact within the system.

IX. Elaboration on the Pivoting Mechanism

The most significant remedy that we present in this report for the incoherence and silo frame of mind that prevails in the NSI, is the pivoting of the HESTIIL towards an institutional arrangement that will redress fragmentation, improve system performance and monitoring,

and promote cooperation and the development of synergies. Once properly configured, the reconstructed HESTIIL will be in a position to deliver on the NDP objectives and enhance social and economic impact through targeted uses of incentives, grants and other policy instruments. The HESTIIL Review Panel is convinced that the measures contained in this report, which are motivated largely by the NDP, are consistent with and can be implemented under the banner of the STI White Paper.

To support the recommendations outlined above, we provide further details on the key components of the pivoting of the HESTIIL that is proposed. In particular, we elaborate by presenting an outline of the elements that constitute the spine of the reconfigured HESTIIL, viz:

- The proposed steering mechanism or governance structure (i.e. the coordinating framework);
- A reconfigured institutional base for implementing all the approved RDI programmes of the NSI, including the grand challenges (under the stewardship of the proposed new National Foundation for Research and Innovation); and,
- The suggested catalytic trans-disciplinary societal grand challenges (or missions).

A. The National Coordinating Framework

As part of transitioning to the idealised landscape, we propose the establishment of a four-level agenda and priority setting, steering, implementation and monitoring mechanism, to be constituted as follows:

- *First Level: The Presidential Advisory Council/Plenary for Science and Innovation*

  The Presidential Advisory Council/Plenary for Science and Innovation will be chaired by the President. It will comprise high-level representatives from the cross-section of the NSI, including business, industry, government, higher education, non-governmental organisations and civil society. The principal role of the Presidential Advisory Council/Plenary will be the setting, reviewing and updating of the country's mid- and long-term policy agenda for science, technology, innovation and industrialisation. The Council/Plenary will also consider and provide specific advice, knowledge and guidance to government such as in the instance of the Research Development and Innovation societal grand challenges or missions. It will also publish medium-term agendas or strategy documents for research, innovation and industrialisation. A reconstituted, as well as mission and capacity reinforced, National Advisory Council on Innovation (NACI) will provide advisory and secretariat support to the Presidential Advisory Council/Plenary.

- *Second Level: Inter-Ministerial Panel*

  Operating under the oversight of the Presidential Advisory Council/Plenary will be a panel of ministers from all the sectors that have a critical stake in higher education, science, technology and innovation. Chaired by the Minister of Higher Education,

Science and Innovation, the Inter-Ministerial Panel will be responsible for steering, monitoring, evaluation and remediation (when and where required) of the NSI.

- *Third Level: Inter-Departmental Group*

  The Inter-Departmental Group is a Director-General (DG)-level structure that will also include apex leaders of universities, science councils and agencies organised within knowledge, innovation and technology transfer and industrialisation fields/clusters/councils. The Inter-Departmental Group will be responsible for implementing the NSI agenda, inclusive of all programmes and societal grand challenges/missions.

- *Fourth Level: The National Foundation for Research and Innovation*

  As a long-term goal, i.e. to be established by 2030, the various HESTIIL entities will be reconstituted as science councils or clusters into the National Foundation for Research and Innovation (NFRI). The NFRI constitutes the science, technology and innovation spine of the NSI. Details on the NFRI are discussed below. In the short- to medium-term, the various HESTIL entities will be reconstituted as science councils/clusters under the Inter-Departmental Group.

In summary, the National Coordinating Framework will address the fragmentation and incoherence that is endemic to the NSI, through high-level steering and agenda setting, integrated monitoring and evaluation, and coordinated implementation plans. These will be executed through an appropriately resourced inter- and trans-disciplinary institution that is primed for pivoting the performance of the NSI towards the achievement of the NDP goals.

At a glance the National Coordinating Framework is constituted as follows:

	Presidential Advisory Council/Plenary	**Inter-Ministerial Panel**	**Inter-Departmental Group**
Role	Agenda setting	Steering, monitoring and evaluation	Implementation of NSI agenda
Level	Presidency	Ministerial	Director-General
Type	Advisory	Steering	Working group
Composition	High-level leaders from business, industry, higher education, government, civil society and NGOs	Cabinet ministers from relevant ministries	DGs, apex leaders from universities, science councils, business, industry

Table 1: The National Coordinating Framework
(NB: The NFRI and NACI are not included in the above table.)

B. The National Foundation for Research and Innovation (NFRI)

Transitioning from the "as is" to the "idealised" state of the NSI will culminate in the establishment of the proposed National Foundation for Research and Innovation (NFRI) via a gradual and initially modest resetting process of the current system to achieve greater inter-connectedness, collaboration and partnership. The NFRI will bring under one umbrella various

entities in the innovation system value chain - from those performing basic research, to innovation and technology transfer to commercialisation entities. As the national implementing agency, it would create a seamless innovation funnel to ensure that there are no chasms that stifle industrialisation and the achievement of the country's economic and social goals.

As alluded to above, the shift towards an idealised HESTIIL should be phased in over the next ten years. It will build on existing initiatives, with resource efficiency in mind, via a transitional resetting in the next five years, to develop inter-connected collaboration and partnership. This will involve a gradual and well-considered migration of entities to the National Foundation and Research and Innovation (see Figure 3 below). It is recommended that sufficient time - up to ten years - is allowed for the new entities to be located under the coordination and control of the NFRI, to ensure a thorough and well considered process with minimum disruption.

The HESTIIL Review Panel wishes to emphasise that all the institutions to be established under the NFRI need not be created from scratch. It is recommended that all the entities be constituted from a judicious process of analysis, identification, migration and consolidation of existing institutions and capacities across the HESTIIL. This process can neither be rushed nor forced. This is why it is recommended that a period of up to ten years is set aside to enable careful analysis and planning, as well as to implement the actual migration processes. The institutional reconfiguration process that will bring about the NFRI will be complex as it will entail the migration and consolidation of various entities with diverse mandates and institutional arrangements. However, with appropriate planning and care, the process can be implemented with minimum disruption, particularly on the part of those engaged with the RDI activities.

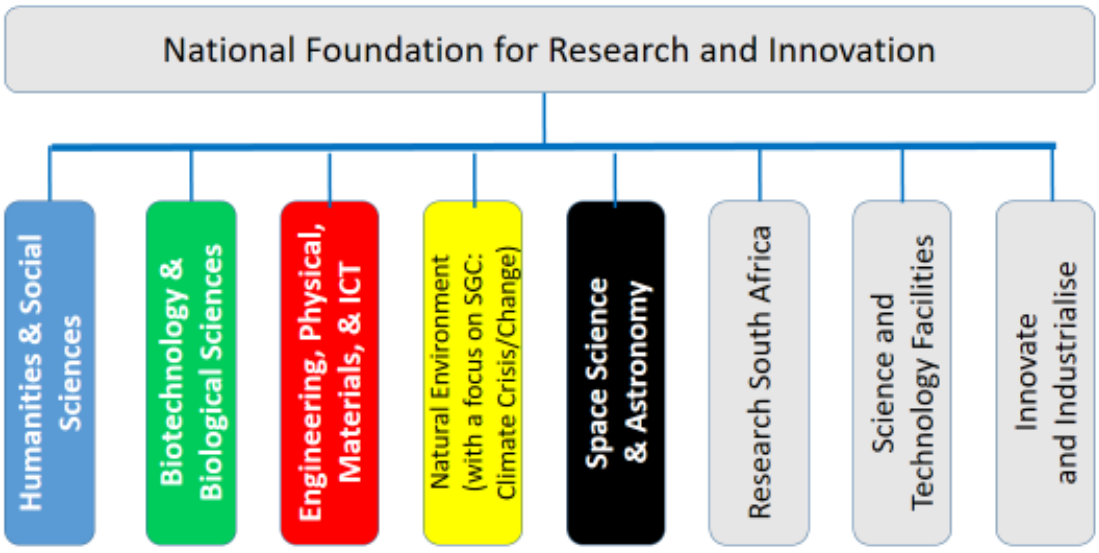

Figure 3: An Indicative Institutional Model for an Idealised HESTIIL*
(*The RDI disciplines of the new entities under the NFRI can be organised in different permutations.)

C. The Research, Development and Innovation Missions

In conducting the capacity analysis of HESTIIL, the Review Panel gave considerable focus and attention to examining the size, shape, direction, responsiveness and impact of the research and innovation and the higher education systems. This included the identification and examination of Research Development and Innovation (RDI) activity and capacity across the NSI that is aligned with the STI White Paper, the National Plan for Post-School Education and Training as well as the Report of the NACI Foresight Study.

The pivoting of the HESTIIL to address the existing gaps and shortcomings should take place alongside a reconfiguration of the research agenda to add a special focus on the key developmental challenges facing the country. To this end, the practice of identifying trans-disciplinary societal grand challenges or missions is appropriate. The RDI missions will help to catalyse concentrated focus, for given periods of time, to respond to some of the key socio-economic challenges of the country. While the overall STI agenda will continue to be implemented across the HESTI landscape, in accordance with the approved national and organisational plans, the societal grand challenges or missions will earmark special domains that require sustained RDI activity.

Our system capacity analysis, and an in-depth examination of the NDP goals, led to the identification of four RDI areas that could constitute the catalytic missions for a re-imagined HESTIIL and a socially responsive agenda. The four proposed missions met all the criteria that were applied to this prioritisation exercise. They also support the country's value system and would contribute towards pivoting the system towards greater collaboration.

Arising from the analysis of the HESTIIL Review Panel, the following four societal grand challenges or missions are recommended for implementation:

I. **Health and Well-Being** - which would allow setting in place pro-active efforts to deal with all communicable diseases that affect communities, improve life-expectancy and achieve food-sovereignty and nutritional democracy.

II. **Climate Crisis/Change** – sustaining the integrity and enhancement of ecosystem services and their relation to an improved quality of life.

III. **Work, Livelihoods in a Changing Technological World** - responses that redress vital, gender, race, class, generational, income and household inequalities; and,

IV. **Learning, Education and Scholarship for a Future Society** - to enhance the pro-active scientific, technological and interpretative capacities in the system.[31]

The above priority societal grand challenges or missions offer these distinct advantages:

- They outline programmatic areas to direct multi- and trans-disciplinary RDI initiatives over and above the traditional research agendas of the NSI and its institutions.

[31] After listening to the Decadal Plan ideas for Challenges carefully, we were convinced to take out "Learning" from Challenge no 3 because it pertained to all other areas as well and create an area in its own right.

- They provide a platform for the country's priorities to be succinctly communicated with increased clarity and precision to all the country's citizens and other stakeholders.
- The missions can form the bases for coordination across multiple silos in the existing system, within and between government departments, business and industry and civil society.
- They are well positioned to indicate where the opportunities for the scaling up of the NSI should be, as well as the priority areas for developing capabilities for innovation; and,
- Over time, the four missions can provide a platform for South African excellence in some of the most important global challenges, particularly in the developing world.

The process of consolidating the existing programmes into four missions can be accomplished within the framework of the institutional reconfiguration outlined above. This could be done without causing unnecessary disruptions given that the proposed missions are consistent with many elements of the recent priority setting exercise conducted by NACI. For instance:

- Health and Well-Being - it was already prioritised as a Medical/Social research-terrain, it could encompass also "Nutrition for a Healthy Population" and the proposed "Nutrition, Food Security and Food Sovereignty" and also the focus on "Health Technologies."

- Climate Crisis/Change - can absorb the priorities around "Integrated Solutions for Water Security" and enhance the already identified priority in "Earth Sciences, Climate Change and Water Security."

- Work, Livelihoods in a Changing Technological World - could absorb initiatives in the "Circular Economy" cluster, a "High-tech Industry domain", the "Opportunities and Impact of ICTs", the "Marine Sciences and the Ocean Economy", "Sustainable Energy Mixes", and "Industrial Diversification and the Future of Jobs."

- Learning, Education and Scholarship for a Future Society - could absorb the "Education for the Future" and "Sustainable Technologies for the Marginalised and the Future of Society".

Further work that supported the identification of the above missions, and possible reconfigurations that will enable their success includes network mapping. The mappings are based on financial connectivity in all four priorities to give a tangible indication of the state of the respective innovation ecosystems. A full description and presentation of the networking exercise is contained in the comprehensive Review Report.

X. Conclusion

As demonstrated in this review report, South Africa's NSI is at a crossroads. If the status quo is allowed to continue, the NSI will continue to underperform, and will remain plagued by incoherence and discordance. In such an instance, the NSI will fail to generate the benefits of a knowledge economy envisaged by the NDP.

The Review Panel has identified several measures that could be implemented to pivot the HESTIIL towards increased collaboration, coherence and innovation. The strategic levers of change entail:

- A **values** base that is consistent with the NDP vision.
- Institutional **governance** that will ensure collaboration and coordination.
- A smart **resourcing** plan that will optimise and sustain the funding base for HESTI.
- The enhancement of the necessary **capabilities** for innovation and management; and,
- A measured and progressive implementation of institutional changes and RDI societal grand challenges or missions to deliver system **coherence** and synergy.

Chapter 1

Introduction and background

1. Introduction and background

1.1 Introduction

There are compelling reasons for South Africa to look to higher education, science, technology and innovation as key drivers of social development and economic transformation for the country. The causal link between higher education and human development has been established in different contexts[32]. Similarly, long-term cross-national empirical studies have amply demonstrated the positive correlation between scientific development and economic growth[33]. Having unshackled itself from an oppressive order that actively restricted the development potential of the majority of its people, the country carved an economic pathway that is characterised by growing a knowledge and skills base, through increasing expenditure and participation in higher education, science, technology and innovation.

The National Development Plan: Vision 2030 (NDP) places a lot of importance on higher education, science, technology and innovation as crucial contributors to social and economic development. Furthermore, the NDP highlights the importance of knowledge production and application in intensifying industrial development and competitiveness. The NDP also recognises the importance of science and its applications in driving innovation that catalyses economic growth that is so critical for addressing the pervasive social problems of the country. To enhance the capacity of the science, technology and innovation system to support the country's development objectives, the NDP calls for several improvements to the system. Among other recommendations, the NDP called for the country to:

- Sharpen its innovation edge;
- Increase investments in research and development;
- Secure far more efficient use of existing resources;
- Catalyse more nimble institutions that facilitate innovation; and
- Enhance cooperation between the public and private sectors[34].

Furthermore, recognising their central role in the achievement of innovation, the NDP calls for urgent coordination and collaboration between universities, science councils, other government structures, non-governmental organisations and the private sector[35]. The Plan acknowledges that while the sites of knowledge production are dispersed in multiple locations, they need to work together for the common good of the economy:

> *"There are multiple sites of research and knowledge production, which are partly or wholly separated from higher education: in industrial laboratories, government departments, corporate research units, parastatals, statutory research councils and NGOs, or through collaboration between these organisations. It is essential that all these sites of research and innovation are coordinated and function coherently to take advantage of new modes*

[32] Badea, L. & Rogojanu, A. 2012. Controversies concerning the Connection Higher Education – Human Capital – Competitiveness. *Theoretical and Applied Economics* Volume XIX (2012), No. 12(577), pp. 125–142.
[33] Schofer, E., Ramirez, F. & Meyer, J. (2000). The Effects of Science on National Economic Development, 1970 to 1990. *American Sociological Review, 65*(6), 866-887. Retrieved August 19, 2020, from www.jstor.org/stable/2657517.
[34] RSA. 2012. National Planning Commission: National Development Plan Vision 2030. Pretoria: Government Printing Works.
[35] Ibid.

of knowledge production, economies of scale and opportunities presented by working across disciplines."[36]

This HESTIIL review can be regarded as a firm step toward bringing to reality the vision of the NDP of a coordinated and coherent National System of Innovation (NSI) of South Africa. Several prior efforts have focused on identifying the best institutional model for South Africa's NSI. This study builds on preceding work, including previous ministerial reviews and other official and private contributions.

The 2019 White Paper on Science, Technology and Innovation (STI-WP) introduces several policy shifts that take further the quest for a more collective approach to knowledge and innovation, including[37]:

- Increasing the focus on inclusivity, transformation and linkages in the NSI;
- Enhancing the innovation culture in society and government;
- Improving policy coherence and budget coordination across government;
- Developing a more enabling environment for innovation;
- Developing local innovation systems;
- Supporting social and grassroots innovation;
- Expanding the research system;
- Developing human capabilities;
- Accelerating the implementation of the pan-African STI agenda; and
- Increasing investment in the NSI.

Inherent in each of the above policy intentions is the need to develop an inclusive, coherent and collaborative NSI that contributes to the development of all South Africans. To achieve this, there is a need for an institutional model for the NSI that is benchmarked against the best internationally, that will respond to the challenges and close the gaps that currently limit the HESTI institutional landscape of the capacity to fulfil the objectives of the NDP and other relevant policies. Such a model will also have to take on the task of urgently and substantively transforming the manner and purpose of knowledge production to one that is far more diverse and inclusive, and that addresses the country's triple challenge - of enduring high unemployment, debilitating poverty and widening inequality - by contributing to social and economic inclusion, transformation and shared prosperity.

1.2 Background

This Ministerial Review of the Higher Education, Science, Technology and Innovation Institutional Landscape (HESTIIL) takes place during a period of a distinctive confluence of social and economic conditions in South Africa. The country's economy growth has contracted into the negative, prompting the credit rating agencies to downgrade the country to "junk" status. Already by end of 2019, unemployment had risen to its worst levels since 2006. In 2020, when the COVID-19 pandemic wreaked its havoc on the country, the already dire social and economic conditions of the country worsened even further. Yet the gloomy economic situation, in an already poverty stricken and highly unequal society, is not the only concern.

In the past few years, there had been growing public disquiet about rampant corruption in the government and private sectors. Public confidence in the capacity of the state to act in the interests of ordinary people during this period of hardship has diminished. In the 2019-2020 Consolidated General Report on National and Provincial Audit Outcomes, the Auditor-General highlighted a

[36] RSA. 2012. National Planning Commission: National Development Plan. Pretoria: Government Printing Works.
[37] DST. 2019. White Paper on Science, Technology and Innovation. Pretoria.

continuation of irregularities involving maladministration and fruitless and wasteful expenditure across a swathe of government departments and other public institutions across all spheres of government[38].

Access to higher education for students from rural and urban poor families was significantly and correctly boosted by government's national bursary scheme, however the long-term employment prospects for college and university graduates is worrying in a shrinking and deindustrialising economy.

This review takes into consideration similar studies and reviews of the national system of innovation that have taken place in the past. In particular, reference is made of the 2012 and 2017 Ministerial Reviews of the Science, Technology and Innovation institutional landscape. A summary of the recommendations of the two reviews, and how the 2019 White Paper on Science, Technology and Innovation responds to them, is found at **Annexure A**. Some of the issues raised and recommendations made in the two studies receive attention once again in this review. These include:

- Governance of the NSI;
- Financing of the NSI;
- The National Advisory Council on Innovation;
- NSI monitoring and evaluation;
- Human capabilities;
- Role of the business sector; and,
- Coordination of the NSI.

While this review follows upon similar reviews on various aspects of science, technology and innovation in the country, this HESTIIL review is different in that it is the first time that, as a result of the establishment of a single ministry, higher education and science, technology and innovation are all brought into comprehensive purview in terms of this review's reference. Nevertheless, this review takes into consideration the findings and recommendations of all preceding studies.

[38] Auditor-General of South Africa. 2021. Consolidated General Report on National and Provincial Audit Outcomes: PFMA 2019-2020. Auditor-General: Pretoria.

Chapter 2

Approach and methodology

2. Approach and methodology

The terms of reference of this review call for an analysis of the country's Higher Education, Science, Technology and Innovation institutional landscape with a view to proposing an institutional model that would promote coherence and collaboration. The challenge of fragmentation of the NSI has been highlighted in several reports, including the NDP and the STI-WP. The benefits of increased coordination and cooperation are highlighted in the quotation from the NDP cited earlier.

The list of deliverables outlined in the terms of reference of this study include:

- A review report providing an overview of the current higher education, science, technology and innovation institutional landscape and the architecture thereof. The report should include a graphic representation of the landscape.

- An assessment of the current institutional model in South Africa. The report should cover the shortcomings and positive attributes of the current landscape.

- An international benchmarking study identifying different types of institutional models, identifying gaps if any, proposing an appropriate option for South Africa, and stating the criteria for selecting the option.

- Recommendations on the architecture of the institutional model best suited to South Africa's current context and future needs and aligned to the objectives of the two white papers.

- An implementation plan to achieve the proposed institutional model.

In order to realise the objectives of this review and the above deliverables, the review panel gave considerable attention to devising an appropriate approach and methodology. The extent and complexity of the mandate given to the Review Panel called for a range of methodological approaches that enabled the Review Panel to address the key components of the study. In broad terms, these methodological approaches include:

- ***Situational analyses*** *– applying a correlative and evolutionary approach to the SWOT analysis to establish the foundations, pillars and differentiated advantages of the NSI, as well as opportunities to intensify and accelerate it, taking into account the demand for its enhanced and accelerated social and economic impact.*
- ***Capacity analysis*** *– an in-depth examination of the HESTI institutional landscape to establish the scope, scale and depth of the NSI, across various mandates and disciplines, and its absorptive capacity for urgent and focused expansion.*
- ***Institutional landscape mapping*** *– employing heatmaps and other graphics, as well as other analytical tools, to track and identify interconnectivity through resource flows within the NSI and areas that require urgent remediation.*
- ***Case studies*** *– critical analyses of a range of historical NSI initiatives to excavate and elevate NSI project/programme successes and failures, to bring the lessons from these to bear on the review, and to provide for HESTIIL system learning.*
- ***In-depth stakeholder engagements*** *– to source critical insights into high-performing/high-performance NSI actors and to identify for focused attention outliers and institutions/actors requiring realignment and renewal.*

- ***International benchmarking studies*** *– to benchmark SA's NSI against leading industrial economies (viz. South Korea, Japan, Singapore and OECD countries) and comparable industrialising countries or contexts in the developing world (viz. Brazil, China and India); and*
- ***An extensive consultative process with critical state, business and industry and civil society actors within the NSI*** *– these engagements provided platforms to source critical and live insights into the 'as is' NSI, to learn about actors' visions for the desired future NSI, and to test our initial findings and provisional recommendations.*

The first three components, i.e. situational analysis, capacity analysis and the landscape mapping, provided the main organising themes for the work and the report. Each of these components engaged further data-collection methods in the manner described below.

2.1 Situational analysis: Approach and methodology

The approach to the situational analysis takes the form of a SWOT analysis. This is informed by the requirements of the terms of reference. To get the most out of the SWOT analysis, the panel chose to adopt an evolutionary and correlative approach. This would enable the level of depth and rigour that the study called for. Furthermore, we took certain precautions to ensure that the pitfalls that often plague this kind of analysis are avoided. In the introductory section of the situational analysis (see Chapter 3) we provide a comprehensive argument for the selected approach.

Given the wide range of issues and questions that need to be addressed, we employ a blended research design to elicit the breadth, depth and quality of data and information that reflect the complexity of the HESTIIL as a component of the NSI.

Flowing from the nature of the work and the terms of reference, this SWOT analysis comprises three successive levels, namely: (i) data collection, (ii) data analysis and review; and (iii) the formulation of recommendations. At each level of the analysis, specific methods are employed, as follows:

Data collection is largely from secondary sources undertaken through desktop documentary analysis. This is supplemented by insights derived from focus group discussions and in-depth interviews with key stakeholders.

Critical analysis and review are accomplished by means of content analysis with specific attention given to needs analysis of the country in the four identified analytical dimensions, namely values, political economy, systems and people. National planning documents, such as the NDP, as well as the appropriate policies and indicators, are used to establish the country's needs in relation to People, Systems, Political Economy and Values.

Formulation of recommendations was conducted through an adapted Delphi method, complemented by an Idealised Design process. This is a qualitative process that unfolded in the following five-step sequence:

Step 1: Meeting of the expert panel to define the problem and map out the process and parameters;

Step 2: Presentation and discussion of SWOT analytical data derived from the first two stages, namely data collection, and critical analysis and review;

Step 3: Critically appraising the data in a polyphonic dialogue in relation to the overall terms of reference of the review, and taking into account emerging themes, issues and trends from the other components of the review;

Step 4: Proposing, based on the above analysis, a set of recommendations guided by the needs of the country and the unfolding global future.

Step 5: Consolidating inputs from the expert panel using Idealised Design.

The Review Panel serves as the expert panel for the purposes of this exercise.

Each of the three levels of analysis progressively indicates the level of depth involved in the process. All four analytical dimensions (values, political economy, systems and people) are rigorously subjected to the same three-stage methodological research process.

2.2 Capacity analysis: Approach and methodology

The methodology for the capacity analysis involves a desktop review drawing on credible sources of literature on assessments made within identified national priority areas of existing research capacity (that is in terms of researchers, scientific research infrastructure and outputs of knowledge and technology) as well as in terms of deficits. The reference to basic, applied and experimental research as structured in the Frascati Manual of the Organisation for Economic Cooperation and Development (OECD) is used to unpack the socio-economic investment dynamics of the different HESTI institutions, that is the universities, public and business research organisations as well as non-governmental organisations.

The capacity analysis focused on specific requirements in the terms of reference of this review, that is Clause 3.7 (b) and (c), as set out below.

Extract from HESTIIL terms of reference Clause 3.7:

(b) An analysis of the capacity (including financial capacity) of existing institutions to –

(i) Support post-school education and training across the landscape, particularly to achieve its NDP targets.
(ii) Undertake strategic research to produce knowledge spanning the social and natural sciences and the humanities.
(iii) Undertake applied research for policy development and technology development for economic competitiveness and improved quality of life.
(iv) Develop and maintain post-school education, research and innovation infrastructure.
(v) Provide services to help the public and private sectors to stimulate innovation in the country.

(c) An analysis of the higher education, science, technology and innovation institutions to establish programmatic focus, intensity of activity, concentration or dispersion of activity (within and among institutions), and impact on the realisation of policy outcomes.

It is noted that the available literature across each of the priority areas differs considerably in nature (content), form (ranging from scientometric studies to studies that are narrowly focused on universities only or industry participation only) as well as in terms of methodology and purpose. This has made it impossible to use a standard approach for evaluating the performance of these

organisations across all the priority thrusts. For this reason, our capacity analysis aims to provide as much relevant information as possible on the institutions active in each of the selected clusters. The format is therefore structured around the following issues:

(i) Socio-economic context, with line-of-sight of the NDP Vision 2030 goals and the Science, Technology and Innovation White Paper (STI-WP);
(ii) Investments in research and experimental development;
(iii) The research base with a focus on researchers and research infrastructure; and
(iv) Direction-setting and governance.

With regard to research organisations, we draw upon their Annual Reports and Shareholder Compacts that can generally be relied upon as having been subjected to rigorous authorisation processes. Use is also made of review studies undertaken by official advisory bodies such as the National Advisory Council on Innovation (NACI). Specifically, the National Survey on Research and Experimental Development conducted by the Centre for Science, Technology and Innovation Indicators (CeSTII) at the Human Sciences Research Council (HSRC), assessments by the National Advisory Council on Innovation (NACI), review reports by the Academy of Sciences of South Africa (ASSAf), and the recently published scientometric study of the South African Research Enterprise by the National Research Foundation (NRF) and CREST[39], which provide useful reference indicators and insights for this aspect of the report.

The findings were tested on an ongoing basis throughout the HESTIIL review process that included detailed discussions with thought leaders in the fields of higher education, science, technology and innovation.

2.3 Landscape mapping: Approach and methodology

The terms of reference of this review in relation to the mapping of the HESTI landscape suggest the following methodological approaches:

> *"Data should be gathered to identify and categorise the current higher education, science, technology and innovation institutional landscape.*
>
> *A literature review should be conducted that reflects a heat map of sectoral research and development and STI activity and institutional existence/capacity.*
>
> *Interviews with representatives of institutions in the NSI and other stakeholders should be conducted as appropriate."*

To address the above, the panel decided to follow the following approaches:

- Landscape mapping of the NSI;
- Scientometric assessment of the NSI;
- Stakeholder opinions and suggestions; and
- Case studies.

[39] Mouton, J., et al. 2019. *The State of the South African Research Enterprise. DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy*, CREST/SciSTIP. Stellenbosch University 2019.

Making use of triangulation – the application and combination of several research methods in the study of a particular phenomenon – we identified issues of concern and possible relevant solutions. By combining multiple observers, theories, methods and empirical materials, one is expected to overcome the weakness or intrinsic biases and the problems that come from single-method, single-observer or single-theory studies.

2.3.1 Landscape mapping of the NSI

For the purpose of this review, the NSI can be best evaluated from a systems perspective which sees the NSI as a network making up the entire national innovation ecosystem. In this case, system means a grouping of parts that operate together for a common purpose. The system may include people, policies as well as physical parts (e.g. facilities and equipment).

In the mapping exercise each node is expected to describe a part of a system that depends upon a few input variables and results in a few output variables. The system as a whole can be described in terms of interconnections between the nodes.

The types of mapping that were considered were:

- Organogram: power structures and parenting structures;
- Thematic: mandates, disciplines, gaps and overlaps; and
- Geographic: concentration and locality.

The above interconnections are defined as flow parameters representing either financial details, human resources (capacity) or R&D (publications and IP).

2.3.2 Scientometric assessment

Scientometrics is a scientific field by which the state of science and technology can be observed through the overall production of scientific literature and patents at a given level of specialisation. It is a well-developed scientific discipline with its own journals (e.g., International Journal of Scientometrics) and international conferences. It provides an approach for situating a country or scientific discipline in relation to the world, an institution in relation to a country, and even individual scientists in relation to their own peers. Scientometric indicators are equally suitable for macro-analysis (e.g., a given country's share in global output of scientific literature over a specified period) and micro-studies (e.g., a given institute's role in producing articles in a particular field or specialty of science).

The use of scientometrics is a widespread international phenomenon. So, for example, it is used to measure research progress against a set of priority research areas such as the European Commission's FP7 priority areas (Hassan et al., 2012) and to advise the president of the United States (NSF, 2020) and other national and global leaders.

For the purposes of this review, we provide indicators which make a policy contribution to the review's project objectives.

2.3.3 Stakeholder opinions

Interviews are a qualitative research technique which involves asking open-ended questions to converse with respondents and collect data about a subject of interest.

The HESTIIL Panel interviewed members of the executive/management of 31 research organisations. In addition, the Panel consulted with Universities South Africa (the association of university vice chancellors), 36 participants from business and industry entities, and 23 participants from civil society organisations. Most organisations sent more than one delegate. Several stakeholders made presentations and a smaller number even sent to the Panel additional submissions after these consultations. On average, each organisation was engaged with the Panel for approximately one hour and thirty minutes.

2.3.4 Case studies

A case study is a research strategy and an empirical inquiry that investigates a phenomenon within its real-life context. Case studies are based on an in-depth investigation of a single individual, group or event to explore the causes of the underlying principles. The ultimate objective is to learn from the findings of the case study and to repeat beneficial actions and avoid detrimental ones.

The HESTIIL Panel debated which case studies would be more useful. Topics included the Technology and Human Resources for Industry Programme (THRIP); the Pebble Bed Modular Reactor (PBMR); the Unrealised Dream of South Africa's Joule; Sasol ChemCity and many others. These elicited useful insights that informed our findings and recommendations.

As outlined above, under each of the three main themes of the review, a unique blend of methods was applied for data collection and analysis. Stakeholder consultations, international benchmarking and case studies were some of the crosscutting inputs into the analytical process across all three themes. In the final analysis, issues and findings were collectively identified that informed the recommendations of the review. The accompanying figure depicts the dynamic and non-linear process flow.

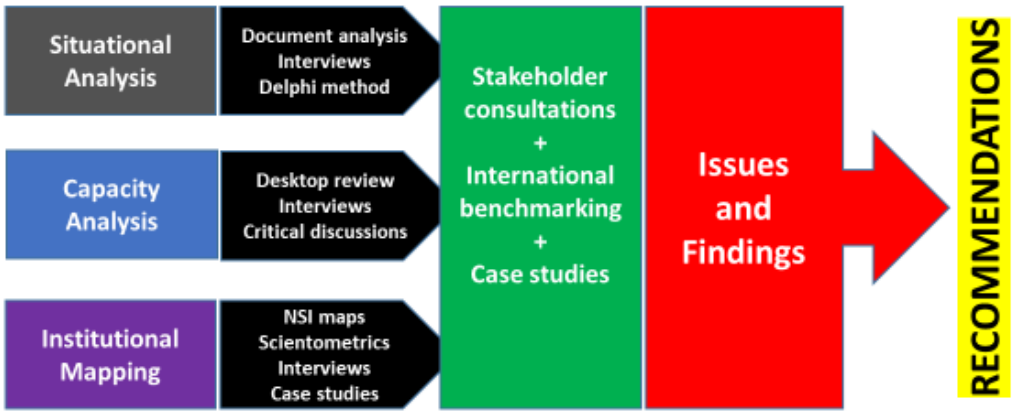

Figure 2.1: Approach and process flow of the review

The finer details of the methods applied in the three main components of the review are detailed in the relevant sections below**. Chapter 3** sets up the report by providing a broad Situational Analysis of the HESTIIL. This is followed in **Chapter 4** by the NSI Capacity Analysis which provides an in-depth review of the system to the level of RDI clusters. **Chapter 5** constitutes the Institutional Mapping of the HESTIIL, which serves to provide a detailed description of the system as a whole and of some of the components, using various analytical lenses. Key Issues and Findings are outlined in **Chapter 6.**

This is followed by a comprehensive presentation of the Recommendations and Implementation Roadmap in **Chapter 7**.

It has not been possible to incorporate all the data collected into the main body of the report. Therefore, valuable data is found in the several **Annexures** to the report. The annexures include the working group reports; international benchmarking exercises; analysis of previous reviews; additional network maps; and other resources as outlined in the main contents page.

Chapter 3

Situational analysis

3. Situational analysis

3.1 Why a SWOT analysis?

This review culminates in recommendations for an institutional model for HESTI that the panel believes is most appropriate for South Africa; one that will help fulfil the needs of the country and which is aligned to the policies, plans and goals of the NDP. This model can also serve as a basis for future planning and allocation of resources. Therefore, this situational analysis, based on a creative application of the SWOT analysis, provides a foundation for future strategic planning. A complete understanding of the strengths, weaknesses, opportunities and threats that pertain to the HESTIIL will form the basis for making strategic choices for shaping, not only the best available institutional model for the country, but also a theory of change that will help align the NSI with the country's needs.

South Africa's NSI, and the HESTIIL within it, are not insular islands. Within the NSI, the HESTI system exists together and in dynamic contact with other systems that make up the NSI. The NSI too is not an entity entirely on its own; it exists and interacts with other systems within a broader universe of sectors and enterprises that are part of the human experience. South Africa as a whole is inescapably immersed in a global field of industry, financial flows, interests, trends and forces that shape the reality of the 21st century world. These connections between various systems, at different levels of analysis, are enhanced, perpetuated and accelerated by the pervasive effect of information and communication technologies. A SWOT analysis provides planners with the ability to systematically examine both the internal and external realities; and, for an entity under consideration, to formulate strategies that will help to hone its competitive advantage. Although it is a simple tool, the SWOT analysis is an effective means of "sizing up an organisation's resource capabilities and deficiencies, its market opportunities, and the external threats to its future".[40]

A deep and honest analysis of the key aspects that shape the NSI is crucial for the development of a model for a future HESTIIL. It is incumbent upon this review therefore to take proper stock of the externalities and internalities concerned with the NSI in order to formulate a balanced perspective of its strengths and weaknesses in the light of relevant environmental opportunities and threats.[41] In conducting the SWOT, comparisons are inevitable as strengths and weaknesses can only be perceived in relation to something else that bears similar properties. At times, comparisons will be made between South Africa's NSI and comparable systems abroad. Comparisons will also be made between the system as it currently exists and of it at another time in the past. Furthermore, comparisons will be drawn between the current reality versus an idealised or desired future state. The different permutations will become evident as this discussion unfolds. Ultimately, all the various analyses are intended to lay a well-argued and evidence-based foundation for an improved HESTIIL.

Although the SWOT analysis has its roots in business strategy, it has been effectively employed in public policy formulation in a wide range of sectors and contexts. However, despite its popularity in strategic planning, the SWOT analysis has come under intense criticism for: indulging only in shallow description[42]; lack of theoretical depth[43]; and, for failing to demonstrate how internal and external

[40] Thompson, A. A., Strickland, A. J. & Gamble, J. E. 2007. *Crafting and Executing Strategy–Concepts and Cases*, (15th Edition), USA: McGraw- Hill/Irwin.
[41] Gürel, E. & Tat, M. 2017. SWOT Analysis: A theoretical review. *The Journal of International Social Research*, Vol. 10 (51): 994-1006, August 2017.
[42] Hill, T. and Westbrook, R. 1997, "SWOT analysis: It's time for a product recall", *Long Range Planning*, Vol. 30, No. 1, pp. 46–52.
[43] Nixon, J. and Helms, M.M. 2010, "Exploring SWOT analysis – where are we now?: A review of academic research from the last decade", *Journal of Strategy and Management*, Vol. 3, No. 3, pp. 215–251.

factors are interconnected.[44] The latter point is of particular concern given the fact that local innovation systems have become a lot more penetrable to external input and are no longer predetermined, owing to the wide-ranging sources and effects of globalisation. For instance, through foreign direct investment and other means of acquisition, within a local industrial ecosystem there are multinational entities that operate within and are part of the NSI, and yet they remain answerable to powers external to the local system. Hence, in the SWOT analysis, an examination of the internal and external variables needs to take into account this reality.

Perhaps the most important criticism to avoid in the application of the SWOT analysis is the lack of an evolutionary perception of the internal and external realities of the system.[45] This pitfall leads to static, sterile and superficial lists of strengths, weaknesses, opportunities and threats, framed in absolutist terms and based on a dichotomous juxtaposition of the internal and external aspects of the entity under analysis.

This study avoids the above pitfalls in a number of ways. Firstly, it takes into account the fact that the internal and external realities do not exist in an isolated binary configuration that dictates a split examination of their properties. The HESTIIL exists in a dynamic and fluid equilibrium with its broader social, economic and political environment. Secondly, this SWOT analysis recognises that there are no absolute threats or opportunities to South Africa's HESTIIL. Any identified threats and opportunities can hinder or advance progress, depending on how the system is predisposed in relation to its strengths and weaknesses. Therefore, in conducting the SWOT analysis, an evolutionary and correlative approach is taken in understanding South Africa's HESTIIL and the dynamic environment in which it exists and operates. Thirdly, to complement the first two approaches, the HESTIIL is not analysed in isolation. A concomitant analysis is made of the wider political economy and the foundational values that shape South Africa's NSI.

A final antidote to the pitfalls that come with a conventional application of the SWOT is the foregrounding of the country's needs, in the context of possible futures that define the HESTIIL. While a careful analysis of the strengths, weaknesses, opportunities and threats can be useful, it is doomed to completely miss the mark if it eschews the needs of the country and the unavoidable reality that unfolds in the environment. Irrespective of the results that a SWOT analysis generates, the needs and future realities constitute additional and necessary aspects that need to be taken into account in strategic planning.

When rigorously applied, and the above pitfalls are avoided, the SWOT analysis can be a powerful tool for strategic management. The dynamic and correlative approach to the SWOT analysis outlined above, provides a platform for establishing the properties of the NSI's strategic "fortresses"[46]. This is accomplished through scanning the dynamic internal and external environment of the HESTIIL to establish the latent capabilities and unexplored powers that could render it formidable, in the face of enormous challenges locally and relentless competition globally.

3.2 Approach to the SWOT analysis

3.2.1 Theoretical grounding

[44] Popescu, F. and Scarlat, C. 2015. Limits of Swot analysis and their impact on decisions in early warning systems, *SEA: Practical Application of Science*, Vol. 3, No. 1, pp. 467–472.
[45] Vlados, C. 2019. On a Correlative and Evolutionary SWOT Analysis (February 19, 2019). *Journal of Strategy and Management*, 2019, Vol. 12, No. 3, pp. 347-363.
[46] Dagnino, G.B. and Cinici, M.C. 2015. *Research Methods for Strategic Management*, Routledge, New York.

In order to provide a proper assessment of the NSI and the HESTIIL, in a manner that avoids the common shortcomings of the traditional application of the SWOT analysis, the HESTIIL Review Panel adopted a correlative and evolutionary perspective on the system. The NSI is viewed as an active, constantly changing system that is continuous, co-creating dynamically with its external environment. In this perspective, the NSI is not a passive and reactive entity that is at the mercy of local and global socioeconomic vicissitudes. As a dynamic system of institutions and organisations, it actively shapes and reshapes the structure and processes that inform the production, application and exploitation of knowledge and technologies to benefit industry, commerce and society.

An evolutionary approach to the SWOT analysis gives precedence to the need for a proper understanding of the NSI. A proper assessment of the NSI looks at both internal and external factors to judge the relative strengths and weaknesses of the system. This avoids a static and myopic assessment of strengths and weaknesses. For example, while it could be argued that South Africa has a strong and sophisticated minerals sector, this cannot be viewed in isolation from the growing effect of imports from other major global players such as China. Therefore, the assumed strength in the minerals sector is by no means absolute as it may appear when looking only internally, as might be the case in the traditional application of the SWOT analysis. Likewise, considerations of the weaknesses, opportunities and threats will not be realistic without a thorough study of the applicable sources and causes, and a systematic analysis of comparative variables both internal and external to the NSI. Therefore, this SWOT analysis is conceived to take a correlative analysis between internal and external factors.

Flowing from the above, the Review Panel proposes a perspective of the NSI that does away with absolutist “good” or “bad” verdicts on the system; and adopts, instead, the more nuanced “better than” or the “worse than” in specific areas, derived from a focused comparative analysis in an evolving perspective.[47] Adopting this correlative and evolutionary approach to the analysis of the NSI will enable a design of an institutional model that is not predicated upon static strengths and weaknesses of the past, but on the structurally evolving dynamic of the system with the environment that will define the future.

The aim of this review is to inform the development of a new HESTI institutional landscape. The HESTIIL occurs at the confluence of people (the bearers of knowledge), technology and innovation within the NSI. The NSI is enmeshed in a wider socioeconomic environment that extends globally. This expansive web of external factors presents to the NSI a dynamic blend of opportunities and threats. A strategic management of the NSI requires ongoing decision-making as to how to respond to the opportunities and threats, taking into account the prevailing internal strengths and weaknesses.

As a first step, in view of the challenges outlined above, a proper analysis of the opportunities and threats is conducted in the evolutionary approach previously outlined. The SWOT analysis therefore is part of, and feeds into, a broader strategic management of technology, innovation and people (MOTIP), which are the key drivers of change within the NSI. Elsewhere in the report, the Review Panel addresses aspects that pertain to the MOTIP within the HESTIIL.

When all these components and processes optimally work together, an evolutionary and adaptive development of the NSI ensues as a dynamic response to the ever-changing operating environment. This relationship is illustrated in the accompanying figure.

[47] Robert, V., Yoguel, G. and Lerena, O. 2017. The ontology of complexity and the neo-Schumpeterian evolutionary theory of economic change, *Economics*, Vol. 27, No. 4, pp. 761–793.

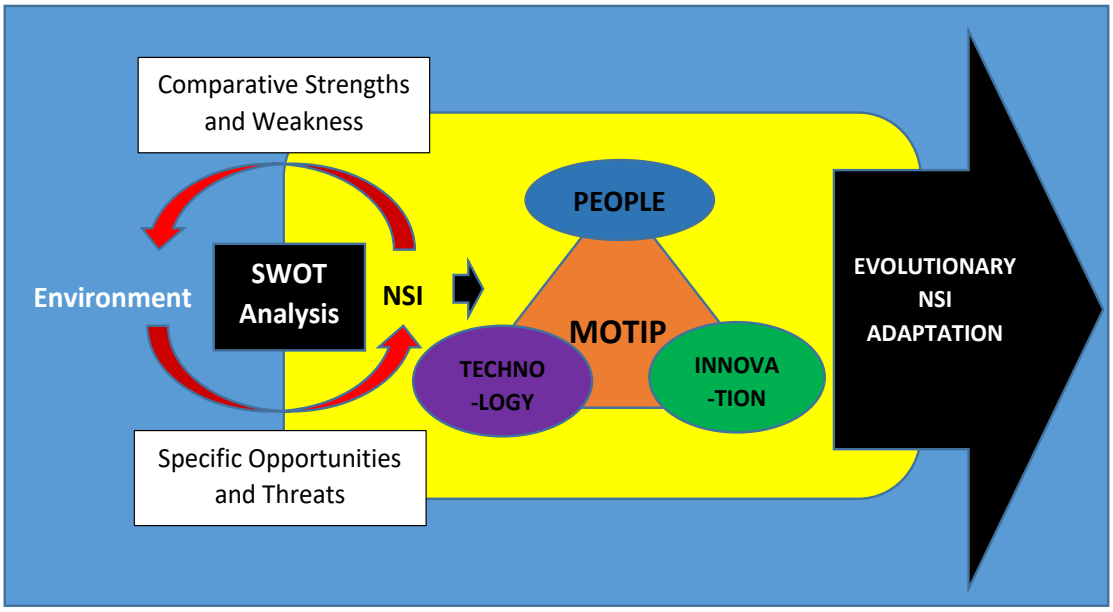

Figure 3.1: Evolutionary SWOT and the strategic MOTIP approach to the NSI

Some of the key questions for the decision-makers that are at the heart of a strategic MOTIP within the HESTIIL are:

- **People**: What constitutes human development? What human capacities does the system need and have? How can we unlock the higher education and science systems to develop the skills and competencies required to position the NSI to deliver on the national development objectives?

- **Technology**: How can we develop, source, integrate and deploy technologies that are appropriate to the country's needs? How can we position these technologies to keep pace with the emerging changes in industry and society?

- **Innovation**: How can we unlock the creative abilities of the people and institutions within the NSI to take advantage of opportunities to deliver value in society and the economy? What are the available opportunities in relation to our capabilities? How do we identify, nurture and unleash the promising innovations to achieve the desired impact?

In this institutional review, the correlative and evolutionary approach to the SWOT analysis provides the basis for strategic decision-making in relation to the key aspects of the NSI, including pointers to an appropriate HESTIIL.

3.2.2 Focus on needs and futures

A SWOT analysis that is decontextualised and lacking in focus will not yield the results that can inform strategic decision-making.

The key policy and planning documents, such as the NDP and the White Papers for Higher Education and Training and STI, outline details of the intended socioeconomic outcomes which provide a point of departure for the SWOT analysis. There are high-level, general socioeconomic priorities, such as poverty reduction, job creation and closing the inequality gap. There are also specific targets to

consider that relate to the country's needs in key dimensions. These needs and targets are used as reference points in the analyses of the selected analytical dimensions discussed below. The SWOT analysis of each of the chosen dimensions is foregrounded by a discussion of the country's needs that pertain to that dimension.

There are broad and all-encompassing emergent themes that have a major bearing on the future, both in South Africa and the rest of the world. For example, new technologies may usher in a new order in education, industry and possibly in society as a whole. Furthermore, in the broader society, new movements and issues could shape the future. For instance, a growing concern for the environment may usher in a future in which issues of sustainability may predominate developmental discourse. These global shifts have the potential to override national policies and plans. Strategic management demands that these possible futures should be taken into account in planning. This SWOT analysis therefore factors in these movements and explores the opportunities and threats they present.

3.2.3 Selection of the SWOT analytical dimensions

South Africa's HESTI system is broad, complex and multifaceted. An exhaustive analysis of all the aspects of the entire institutional landscape is not feasible within the resource limits and time constraints attendant to this review. A choice had to be made about the key areas to constitute the focus of the analysis. The Review Panel decided to concentrate the SWOT analysis on the following four key areas of importance for the HESTIIL:

- **Values**: understanding the principles that undergird our society in a dynamically changing world, including sustainability, inclusion and transformation

- **Political economy**: conducting an introspection of the country's social reality to tease out knowledge and the political economy of innovation to strengthen HESTIIL and buttress future plans and initiatives

- **Systems**: creating an improved landscape that ensures that the country's institutional capacity is well-equipped to deliver an integrated and coordinated national system of innovation

- **People**: examining the human resources research base of the system, taking into account the country's current and future needs

Innovation is a human enterprise. The capacity to innovate is probably the most distinguishing characteristic that separates humans from other animal species. A focus on the analysis of the human resource base is warranted given that people's actions are the most important determinant of change within the HESTIIL. Furthermore, people are the ultimate beneficiaries of innovation efforts. Therefore, all aspects of an evolving institutional model of the NSI should be aimed at advancing human development and well-being.

Systems refer to the content, structure and operations of the NSI and its subsystems. This review is premised on the belief that an appropriate and well-configured HESTI institutional landscape will form the basis for integration and coherence of the NSI. To this end, it is important to understand the composition, structure and mechanics of the system and to identify gaps to be closed and advantages to be leveraged.

South Africa's NSI does not exist in isolation; it is embedded in a broader political economy that has a particular history, structure, entities, idiosyncrasies, interests and power relations, among many other

defining elements. It is not possible to understand the NSI and the institutional landscape within it without developing solid insights into the political economy they inhabit.

Inclusivity, sustainability and transformation are some of the desired outcomes that guide this institutional review. These are some of the values that are contained in South African policies and plans across sectors. Inclusivity, sustainability and transformation can be regarded as components of a much broader value system of the country. A strong message that came out of the interactions of the Review Panel with key stakeholders is that values need to underpin South Africa's NSI. The Panel discussed this at length and concluded that an understanding of the underpinning social values, and how the system has thus far fared in relation to them, can enhance future efforts at institutional planning. It is on this basis that values are incorporated in this analysis.

The four analytical dimensions that frame this SWOT analysis were strategically chosen to bring about focus, structure and succinctness in the analysis, while serving as sufficiently wide lenses with which to explore all the critical aspects of the HESTIIL. Consideration was also given to the need to contribute new insights by covering previously less explored dimensions of the NSI and by contributing new analytical approaches.

While each of the four dimensions is distinct and substantive, there is a logic that threads them into a strategic analytical whole. This is best illustrated in the following diagram:

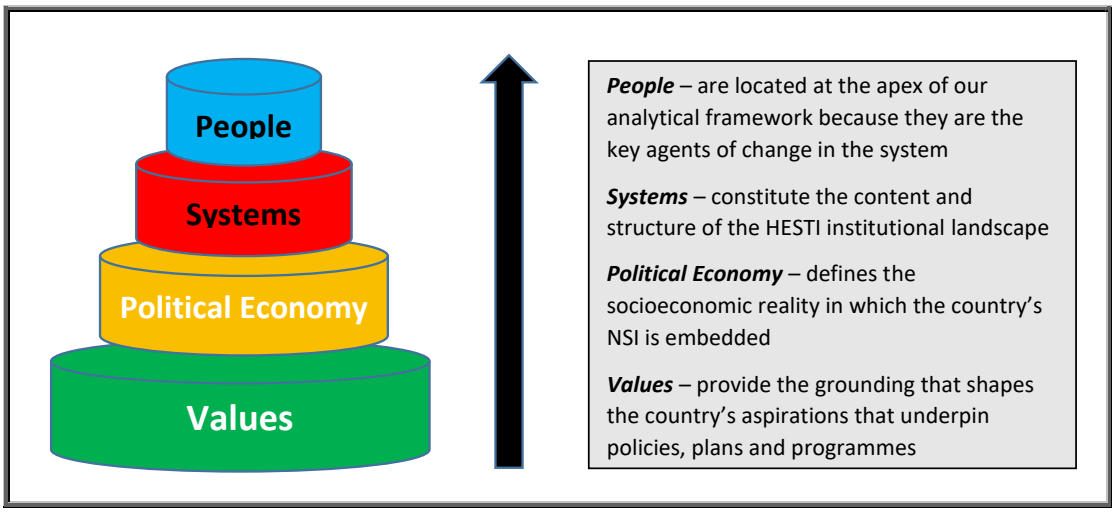

Figure 3.2: An illustration of the analytical dimensions of the SWOT analysis

The arrow that is pointing in the upward direction signifies two elements of the logic that connects the dimension in focus. Firstly, it indicates an increasing level of detail immanent in the dimension, progressively increasing from values to political economy, systems and then people. For this reason, in applying the SWOT in relation to people, it is possible to factor in quantitative measures such as full-time equivalents and numbers of PhDs, etc. However, the level of such concreteness diminishes as the analysis moves to the other dimensions. The analysis of values, for instance, is comparatively more interpretive and qualitative compared to that of systems or people. A key implication of this is that the level of specificity of impact of values on the country's HESTIIL is lower than that of people, for example. Although these dimensions should not be applied in isolation from one another, it is evident that as you move from bottom to top, there is demonstrably a higher correlation between cause and effect in relation to the impact of a dimension to specific system outcomes.

Secondly, each dimension is defined by the one directly below it. Values apply more broadly conceptually than the political economy. The system, which is the NSI in this discussion, is a construct within a broader political economy, and so on. For this reason, the way in which we define the NSI or HESTIIL delineates the subset of the human capital base that is applicable to defining people in this narrative. Similarly, South Africa's NSI is very much a manifestation of the country's political economy. The Review Panel argues that a proper understanding of the NSI can only be achieved when the underlying political economy is clearly defined. It is for this reason that care should be taken when comparisons are made between the local system and corresponding systems abroad.

The relational logic between the dimensions that are applied in this SWOT exercise bears far-reaching analytical implications. As demonstrated in some of the examples, certain flaws in the NSI are manifestations of malfunctions either in the political economy or in the broader value system. An appropriate level of analysis is a prerequisite for strategic policy interventions.

As we delve into the SWOT analysis, using each of the above dimensions to probe into the HESTIIL, a comprehensive discussion of the key concepts and how they relate to the analysis precedes each section. Each analytical dimension is examined, applying the correlative and evolutionary approach outlined above, to surface, on one hand, the threats and weaknesses that beset past and future plans, and, on the other, opportunities and strengths that could serve as a platform for positive change. Taken together, these dimensions serve also as a framework for offering fresh perspectives on previous analyses in order to inform new approaches to the HESTIIL.

Throughout the SWOT analysis, the focus will remain on the NSI with particular attention given to the role of the HESTI institutional landscape within it. To take some aspects of the above further and for the purposes of illustration, the analysis delves into STI disciplines, industrial sectors and other segmentations that are relevant to innovation. However, any insights derived from such disaggregation, e.g. those generated by means of a case study, are applied in order to address the key objective of the overall study, namely to review the HESTIIL with a view to identifying any gaps in the existing institutional landscape, and to propose a model that could enhance the promotion of coherent, integrated and optimised mandates across all the significant components of the NSI. Therefore, while the review, at times, cascades into different levels of depth and detail in probing the various moving parts that constitute the NSI, the overall unit of analysis for this study remains the HESTIIL as a whole.

3.2.4 Reflection on the methodology and the data-collection process

As indicated above, this review sets out, among other things, to provide a comprehensive definition and description of the HESTIIL that currently prevails in the country. The SWOT analysis contributes to this by examining the state of collaborations within and amongst various sectors, institutions and programmes within the institutional landscape.

South Africa faces severe and ever-increasing social and economic challenges that are multifaceted and complex. It is worth appreciating that finding solutions to these challenges will be better served through effective collaborations amongst all institutions and organisations that constitute South Africa's NSI, including universities, research institutions and all the industrial sectors, both public and private. Indeed, the strength of the NSI derives from the quality of the collaborations of its constituent parts. The SWOT analysis therefore has to probe into the heart of these collaborations in order to lay bare the state of their quality, and measure it against the country's needs in the context of the unfolding global trends that are shaping the future.

Given the wide range of issues and questions that need to be addressed, a blended research design is being employed in the analysis in order to elicit the breadth, depth and quality of data and information that reflect the complexity of the HESTIIL as a component of the NSI. However, owing to the limitations of the review, particularly that of time, the analysis is conducted as follows.

Flowing from the nature of the work and the terms of reference, this SWOT analysis comprises three successive levels, namely: (i) data collection, (ii) data analysis and review; and then the (iii) formulation of recommendations. At each level of the analysis, specific methods are employed, as follows:

Data collection is largely from secondary sources, through desktop documentary analysis. This is supplemented by insights derived from focus group discussions and in-depth interviews.

Critical analysis and review are accomplished by means of content analysis with specific attention given to needs analysis of the country in the four identified analytical dimensions. National planning documents, such as the NDP, as well as the most appropriate policies and indicators are used to establish the country's needs in relation to People, Systems, Political Economy and Values.

Formulation of recommendations was conducted through an adapted Delphi method, complemented by an Idealised Design process. This is a qualitative process, unfolded in the following five-step sequence:

Step 1: Meeting of the expert panel to define the problem and map out the process and parameters.

Step 2: Presentation and discussion of SWOT analytical data derived from the first two stages, namely data collection and critical analysis and review.

Step 3: Critically appraising the data in a polyphonic dialogue in relation to the overall terms of reference of the review, and taking into account emerging themes, issues and trends from the other components of the review.

Step 4: Proposing, based on the above analysis, a set of recommendations guided by the needs of the country and the unfolding global future.

Step 5: Consolidating inputs from the expert panel using Idealised Design.

The Review Panel serves as the expert panel for the purposes of this exercise.

Each of the three levels of analysis progressively indicates the level of depth involved in the process. All four analytical dimensions outlined above are rigorously subjected to the same three-stage methodological research process.

3.3 Values

"We know our history and that of other peoples. We have clear values." – NDP, Vision Statement

"Coherence is strengthened when values, information and competencies are shared." – White Paper on STI, Section 3.3.4

3.3.1 Introduction

At the heart of this review is the challenge to bring about a coherent, well-functioning and coordinated NSI. Elsewhere in this report, attention is given to institutions, systems and processes that make up the system to explore means to bring about improvements in system coordination and performance. Due attention is given to the usual factors that are critical for resourcing the NSI with the necessary means to function including people, finances, science infrastructure and equipment. This section turns to a dimension of the NSI that is less prone to measurement, often ignored in scholarly analyses and yet critical for shaping and regulating social relations. In one of the quotations cited above, the White Paper on STI makes a direct link between system coherence and shared values. The following analysis examines the status of this link, within the HESTIIL, and explores opportunities to optimise coherence through a commitment to shared values.

The NSI, and the HESTIIL comprised within it, are social systems. Even though the content and operations of the NSI are designed to achieve cutting-edge results in science, engineering and technology, the system is subject to the direction and influence of human beings. It has been demonstrated that the NSI is a self-organising, adaptive social system[48]. People are at the centre of the functioning and performance of the NSI and, as argued elsewhere in this report, they are the most powerful driver of change. While structures, systems and processes are important variables in evaluating the functioning and performance of the NSI, human agency is the prime driver and deserves due consideration. In this perspective, values are an important aspect of the functioning of social systems.

The NDP references the importance of values in a variety of contexts in society in no less than 56 instances. In particular, the NDP calls on adherence to values in advocating cooperative social behaviour.

> *"Unity in diversity will be fostered by a shared commitment to constitutional values. The values entrenched in the Constitution and its Preamble and further expanded upon in the Bill of Responsibilities are part of children's education and should also be promoted amongst adult South Africans."*[49]

"Unity in diversity" is an ideal that could not be more apt in the discussion of the NSI given the wide variety of institutions and organisations that comprise it, as well as the diversity of people who play various roles within it. For the country's people to work together towards a common destiny, a framework of shared beliefs that forms the basis for common purpose is necessary. These common values are deemed to be so fundamental to nation-building that they need to be taught from an early age and be carried through to adulthood. As prompted by the NDP, we look to the country's Constitution to provide a platform to develop this values discussion.

All organs of state are required by law to cooperate[50]. Chapter 3, Section 41 (1) (h) of the Constitution reads as follows:

> *All spheres of government and all organs of state within each sphere must-*
> *(h) co-operate with one another in mutual trust and good faith by-*

[48] Manzini, S.T. 2011. *South Africa's National System of Innovation: A systems, chaos and complexity perspective*. The Da Vinci Institute for Technology Management. PhD Thesis.
[49] RSA. 2012. *National Planning Commission: National Development Plan*. Pretoria: Government Printing Works.
[50] RSA. 1996. *Constitution of the Republic of South Africa*, Chapter 3, Section 41.

(i) fostering friendly relations;
(ii) assisting and supporting one another;
(iii) informing one another of, and consulting one another on, matters of common interest;
(iv) co-ordinating their actions and legislation with one another;
(v) adhering to agreed procedures; and
(vi) avoiding legal proceedings against one another.

Based on the country's Constitution alone, it is unlawful for public sector organisations within the NSI not to cooperate. At the very least, in terms of the supreme law of the country, public research institutions ought to support one another, share information, consult and coordinate their actions. Reports and reviews that suggest "inadequate and non-collaborative means of STI agenda setting for the country, insufficient policy coherence and coordination, weak partnerships between NSI actors"[51] are an affront to the Constitution, at least in so far as state organs are concerned.

Before further exploring the basis for developing shared values, including those that are advocated by the Constitution, it is necessary to define values and explore why they are often neglected in policy discourse, particularly in relation to HESTI. The following discussion therefore aims to answer these questions: What are values? Why are they important for the development of the NSI? Why are they often neglected in policy reviews and analyses?

3.3.2 Defining values

There are at least three ways in which policy documents reference values. The first and most common refers to the overarching frameworks that underpin the country's Constitution, as illustrated above. Policy documents across the landscape variously draw strategic guidance from the overarching ideals that are enshrined in the Constitution. The second use of the term is in reference to shared cultural values that inform social development. In the National Water and Sanitation Master Plan, the Department of Water and Sanitation (DWS) invokes values in the definition of development to refer to those aspects that support scientific and technical knowledge, as well as traditional knowledge, to bring about social transformation[52]. A similar use of values is found in the White Paper on Science, Technology and Innovation to refer to societal standards that technological change should take on board. As an illustration, the White Paper on Science, Technology and Innovation refers to values that underpin the socio-technical system in spatial development. Thirdly, values are used as points of departure and organising themes in certain STI concepts. This use of the concept is invoked in DSI's definition of "responsible research and innovation" as well as "social innovation" in the 2019 White Paper. In the latter sense, values are more than add-on qualifiers of STI; rather they are the cornerstone markers of preferred end-states that give direction to education, science and innovation plans, programmes and policies.

Notwithstanding the prolific references to values in public policy, including in HESTI policy frameworks as we have seen above, the term "values" is generally used without any definition. This is problematic on a number of levels. First, it creates confusion about what the policy documents refer to as values. People, particularly those who are entrusted with implementing those policies and plans, are expected to simply "get" the intended meaning without any initiation. Secondly, as we have demonstrated above, values are invoked in different ways, depending on the subject matter or the goals of the narrative in which they are found. The greatest shortcoming though lies in the fact that sometimes references to values are made in non-specific terms, leaving the reader to guess as to what exactly is being espoused. Therefore, despite the preponderance of the use of the concept "values" in HESTI

[51] DST. 2019. *White Paper on Science, Technology and Innovation*. Pretoria.
[52] DWS. 2018. *National Water and Sanitation Master Plan Volume 1: Call to Action* v 10.131. Pretoria.

policies, people who are meant to be the custodians of those values are often left rudderless in relation to the desired expectations. It becomes an even greater challenge to break down those values into actionable decisions in day-to-day leadership and management. This is particularly difficult for those who are uninitiated in the values discourse. Given that social values are scarcely part of the curriculum in higher education, let alone in SET training, it should be expected that an average role-player within HESTIIL would be at a loss as to their meaning and import.

When officials do not have a proper understanding of a formal concept, they might turn to the everyday use of the term for meaning. This option is fraught with problems. People use the term "values" to refer to many different things. Values are often conflated with a host of related but totally different concepts, such as attitudes, traits, norms and needs[53]. This confusion is not confined to everyday use of the term though. It has been argued that the concept "drifts in and out" of various disciplines in the social sciences to refer variously to "interests, pleasures, likes, preferences, duties, moral obligations, desires, wants, goals, needs, aversions and attractions, and many other kinds of selective orientation"[54]. It will be daunting indeed for anybody to navigate the plethora of terms and concepts to independently arrive at an accurate definition of values.

It is impossible to espouse values and give effect to them in practice without internalising them. Furthermore, there are practical limitations to contend with. When managers are confronted by day-to-day challenges that demand decision-making, they routinely need to take into account and try to accommodate a host of consideration and constraints. Unless values are entrenched in the managers' strategic orientation and the organisation's culture and track record, they will find it difficult to call on them to guide practice. Some of the constraints, for example cost, will limit the capacity of an average manager to champion values even when he or she is fully conversant about them. No matter how strongly a manager feels about human dignity – one of the values enshrined in the country's Bill of Rights – if there are no funds in the budget to build toilets for the school children, that value could remain betrayed, unless there are special arrangements made to address this kind of dilemma in the department concerned. Therefore, a strong grounding in values is a necessary precondition in order for both individuals and organisations within the system, to promote the advancement of values in practice.

Values can be classified into individual and social. Individual values generate from the natural disposition of humans to cognitively respond to the world around them. Over time, an individual develops a system of criteria for judging perceptions as either positive or negative. Individual values are therefore defined as socially shared "conceptions of the desirable"[55]. The social dimension of these conceptions emanates from the fact that they are representatives of internal needs mediated by external considerations. For this reason, an individual's values are capable of being "openly admitted, advocated, exhorted, and defended" in socially sanctioned terms[56]. Values serve as standards that are applied in various situations and circumstances to guide action; they serve as transcendental reference points for decision-making, introspection, judgment, evaluation and management practice in relation to high-level socially desirable goals and means to achieve them. Values therefore can be terminal or instrumental[57]. The terminal values, also called prime values[58], refer to conceptions of

[53] Hitlin, S & Piliavin, J.A. 2004. Values: Reviving a Dormant Concept. *Annual Review of Sociology*, Vol. 30, pp. 359-393.
[54] Williams, R.M. Jr. 1979. Change and stability in values and value systems: a sociological perspective. In: M. Rokeach, *Understanding Human Values: Individual and societal*. pp. 15-46. The Free Press: London.
[55] Kluckhohn, F.R. 1951. Cultural Factors in Social Work Practice and Education. *Social Service Review*, 25 (1), 38-47.
[56] Rokeach, M. 1979. *Understanding Human Values: Individual and Societal*. The Free Press: New York.
[57] Ibid.
[58] Dahl, R., & Lindblom, C. 1953. *Politics, Economics and Welfare*. Chicago: University of Chicago Press.

desirable end-states or goals, whereas instrumental goals pertain to desirable modes of behaviour that are used as means of achieving socially worthwhile goals. In this sense, instrumental values can be conceived as conditions and prime values as consequences[59].

When individuals come together, whether incidentally or in structured arrangements as in organisations, the emergence of shared values is inevitable. Shared or social values form the basis for individuals to act in the interest of the common good. At the very least, social values help to mitigate the tragedy of the commons. Given that values can be either terminal or instrumental, only a small number can justifiably be found universally. There is only a finite number of desirable end-states and the idealised modes of achieving them. For this reason, values that can be defined as universal number in the dozens rather than in the hundreds or thousands[60]. The cultural diversity and richness that is found across the world derives, not so much from the differences in values, than from the way in which they are organised or prioritised. Institutional value hierarchies, for example, are important for informing key decisions such as goal setting, budgeting and human resources management. The content of organisational plans and policies thus betrays the value hierarchies that prevail in those organisations, wittingly or unwittingly so. Therefore, a careful analysis of official publications of the organisations within the HESTIIL can reveal the extent to which values are promoted or upheld within the system.

3.3.3 Measurement methods and sources of values

It is possible to quantitatively measure institutional values. There are at least five methods that have been proposed, as outlined in the accompanying table[61]. These methods are based on the assumption that institutional values can be hierarchically arranged in order of importance. Institutions therefore are assumed to leave traces of their value systems in their documents, gatekeepers and clients which can be recovered through systematic investigations conducted through these methods.

Method	Definition
Content analysis	Analysing the documents and reports of an institution in order to extract its values
Personal values of institutional gatekeepers	Measuring the personal values of institutional gatekeepers, such as the executives, scientists or board members, on the assumption that the individual values would be a function of the socialisation process of the institution
Personal values of an institution's special clients	Measuring personal values of individuals that are likely to be influenced by an institution, such as graduates or interns
Perceived values of an institution by gatekeepers	Measuring the perceived values of an institution (i.e., value image) as perceived by its gatekeepers
Perceived values of an institution by its general clients	Measuring the perceived values of an institution by anyone among its clientele

Table 3.1: Methods of measurement of institutional values (adapted from Rokeach[62])

Based on the analyses conducted through the above research methods, comparisons can be drawn between institutions. For instance, it could be possible to employ one or more of the five methods to gain insights into the workings of the HESTIIL at both institutional and system levels. By analysing the

[59] Van Dyke, V. 1962. The study of values in political science. *Journal of Politics*, 43(3), 2–34.
[60] Rokeach, M. 1979. *Understanding Human Values: Individual and Societal*. The Free Press: New York.
[61] Ibid.
[62] Ibid.

order of rankings of institutional values, it is possible to establish similarities or convergences between institutions. If it is assumed that institutions within HESTIIL ought to exhibit some shared core values, the extent to which this is the case can be established by the measurement of value sharing, i.e., the degree to which two or more institutions regard a specific value as important. Accordingly, values can also shift and change within institutions and systems. The above methods also enable an empirical detection and an assessment of the extent of that shift.

The foregoing discussion on the methods of measurement of values demonstrates the empirical base for a systematic study of this dimension of the analysis. For the purposes of this review, we focus on the first method outlined above, namely content analysis. The logical questions that must be addressed are: What are the sources of values for the HESTIIL? What is the basis for their legitimacy?

First and foremost, the Constitution of the Republic of South Africa serves as the point of departure in the development of an inventory of values that underpin the HESTIIL. This approach is justified in the sense that all legislation, policies, institutions and programmes of government derive inspiration from the country's Constitution. Moreover, they are required by law to conduct their roles in accordance with the supreme law of the country. The Constitution is also one of the earliest products of the new democratic dispensation. It was written specifically to heal the country of its past divisions and usher in a new era of national unity. Having been adopted by a government of national unity, and the overwhelming majority of the political parties in the national assembly, it enjoys unassailable legitimacy as the ultimate source of values for this country.

After the Constitution, precedence is given to the National Development Plan (NDP). While there are other national plans and policies that precede it, the NDP is unique in that it is comprehensive and multisectoral. It also has currency in that it is still in force as the country's blueprint for social and economic development. The NDP offers a useful vantage point for identifying and analysing the country's values, as they apply to the NSI and HESTIIL, in that it offers a comprehensive planning context with clearly articulated goals and a well-defined vision for the country. Therefore, value statements that emanate from the NDP are not mere philosophical constructs. They are expressions of commonly held conceptions of the desirable, drawn from all sections of society, which are grounded in a real world of concrete multisectoral plans.

It is essential in this analysis and review to drill down to the level of plans that are closer to the institutions and organisations that are most pertinent to HESTIIL. The relevant White Papers, policies, plans and other long-term strategic publications contain relevant data for a values discussion. They also provide insights into how high-level value expressions in the Constitution and the NDP have been translated into various programmes of implementation in education, science and innovation.

The above approach has two complementary advantages. On one hand, it enables a high-level analysis of national values in a general and decontextualised sense, unencumbered by the vagaries of disciplinary constraints. This provides a rare opportunity for contemplation of the public values in their "purest" form, uncluttered by sectoral concerns, to hopefully get to the bottom of their true meaning and intent. The freedom of contemplation provided by exploring values in their constitutional setting is not meant to be a backward-looking exercise undertaken to merely establish their pristine state. Rather, it provides an analytical vantage point from which to frame new conceptions that make it possible to identify new perceptions, possibilities and opportunities for public values to shape the country's future. On the other hand, at the level of sectoral policy and planning documents, the analysis of the values therein is imbued with contextual flavour that provides insights into how the high-level conceptions are given meaning and agency in practical plans, in the heat of management challenges and constraints at the level of the organisation.

Given the nature of the subject matter, the content analysis is suitably qualitative and interpretive although some quantitative input is judiciously applied. It is undertaken in accordance with the overall evolutionary and correlative approach employed in the rest of this SWOT analysis. Embedded in the analysis is a consideration of the needs of the country in the context of an unfolding future socially, economically and technologically.

Before unpacking the values system that underpins HESTIIL, it is necessary to briefly discuss the rationale and role of values in system development.

3.3.4 The role of values for HESTIL development

South Africa is a relatively new democracy, built from the ashes of apartheid, a system of hatred so abhorrent that it was declared a crime against humanity by the United Nations. The pre-democratic South Africa was characterised by multifaceted division. Racism, tribalism and sexism are just some of the multiple lines of divisions that were enacted and enforced, over centuries, to keep the country's people apart and at loggerheads. The end of apartheid, and the dawn of democracy in 1994, signalled an end to this state-sponsored division. Over time, a whole suite of new legislations, anchored in the new Constitution and Bill of Rights, replaced the labyrinth of divisive laws, policies and institutions that formed the edifice of apartheid. Under a new flag, national anthem and other symbols of a united and free South Africa, a massive effort was invested in nation-building.

A significant part of nation-building involved identifying and advocating shared values. The Constitution making process spearheaded the process of identifying new values for the new-born nation and country. Given the horrendous past that was still fresh in the minds of many of its citizens, there was a need to heal the pains of the past and construct a common base for a shared and prosperous future. The new values would mark a fresh beginning and a roadmap to a shared destiny. The grand mission of nation-building, arguably, remains unfulfilled and in dire need of the continuous investment of effort. While great strides were made during the early formative stage of the development of the new South Africa, the momentum, and arguably the focus, of the development of the country's value system has dissipated. This is a sentiment that was shared by some of the HESTI leaders at the roundtable discussions that were convened to inform this review process.

As outlined above, social values are shared conceptions of the desirable. A society entrusts to the public institutions, and the officials therein, important functions and resources in the hope that these would be attended to with utmost diligence. At a broad level, on the periphery of the official contracts, social values serve as the often-unwritten normative patterns that govern the social contract. Responsible government can be measured by the extent to which the public values are upheld. This brings about increased political legitimacy[63]. South Africa places a high premium on higher education and STI as means to development, both for individuals and society. In the respective policy documents and plans, both education and innovation are expressly expected to play an important role in eradicating poverty, reducing inequality and improving employment prospects in the country. Those that are entrusted with responsibility of stewarding the country's HESTIIL therefore shoulder immense responsibility to the people of the country, particularly the poor and marginalised.

The principal challenge at the heart of this review is the need to foster improved cooperation and coordination within HESTIIL and the NSI as a whole, including the private sector and the NGO sector. What will it take to galvanise all these entities towards a common purpose? Part of the answer is suggested by the White Paper on STI: *"Coherence is strengthened when values, information and competencies are shared."* Shared values provide a common social base for the pursuance of shared

[63] Rokeach, M. 1979. *Understanding Human Values: Individual and Societal*. The Free Press: New York.

objectives. As the vision statement of the NDP aptly claims, South Africa has a rich reservoir of shared values to draw from to chart the way forward for HESTIIL, namely the Constitution. It is here where an inventory of South African values that have a bearing on the HESTIIL commences.

3.3.5 Unpacking South Africa's system values

The Constitution of the Republic of South Africa gives attention to the question of values so much so that it can be regarded as the supreme values document of the country. The Constitution insists that these values apply to every sphere of government, organ of state and public enterprise. The supreme law of the country further demands that all national legislation must ensure the promotion of the constitutional values and principles. The rest of the values are derived from White Papers, policies, plans and other long-term strategic publications that contain relevant data for a values discussion. They also provide insights into how high-level value expressions in the Constitution and the NDP have been translated into various programmes of implementation in education, science and innovation.

The list of values derived out of the above process is as follows:

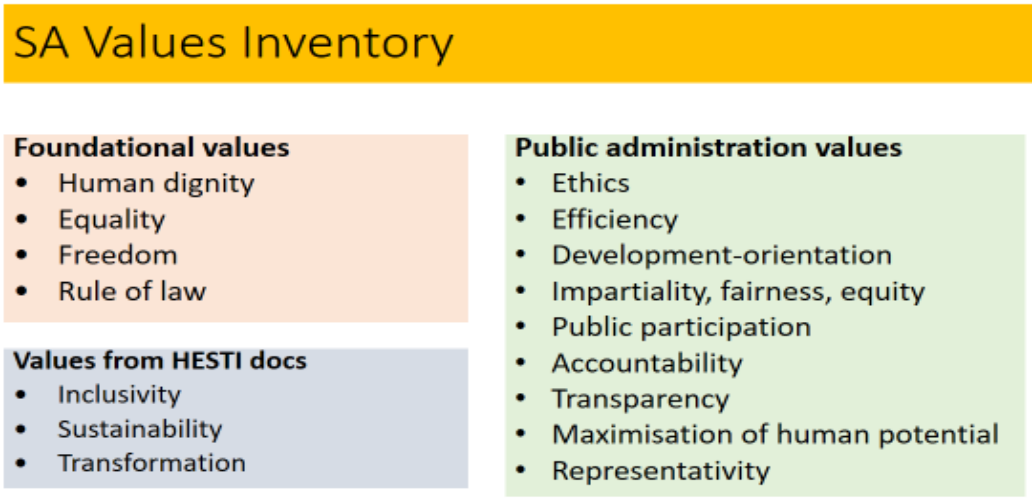

Table 3.2: A sample of an inventory of SA values

The purpose of the foundational values was to lay the foundation for a new democratic dispensation and to heal the wounds of the apartheid past. Decreed right at the introduction of the Constitution, these values form the bedrock upon which all future laws, policies, activities, rules, regulations, processes and practices will be aligned. Every activity involving the citizens of the country should be based on the quest for human dignity, equality, freedom and the rule of law. To underline their importance, these values were repeated in the introduction of Chapter 2 of the Constitution, which lays out the Bill of Rights, a cornerstone of South Africa's democracy.

While the foundational values can be viewed as the terminal or prime values, most of the public administration values could be considered as instrumental values. To the extent to which the public administration values are adhered to, the prime values could be realised. It is important to state that even though the public administration values are meant to provide guidance specifically to all state organs and enterprises, they nevertheless express the common ideals and aspirations that are representative of all South Africans. To that extent, they can be used as benchmarks for all sectors of South African society.

The public administration values have so much import for HESTIIL policy and management that they warrant closer scrutiny. In the accompanying table, the public administration values are listed alongside their descriptions from Chapter 10 of the Constitution. In this analysis, we ask these questions: To what extent have these values been adhered to and promoted within the HESTI system since the dawn of democracy? What are the weaknesses and threats that need to be mitigated? What strengths and opportunities are there in the country's values system that could be harnessed to forge a stronger HESTIIL in future?

Value	Description
Ethics	A high standard of professional ethics must be promoted and maintained.
Efficiency	Efficient, economic and effective use of resources must be promoted.
Development-orientation	Public administration must be development-oriented.
Impartiality, fairness, equity	Services must be provided impartially, fairly, equitably and without bias.
Public participation	People's needs must be responded to, and the public must be encouraged to participate in policymaking.
Accountability	Public administration must be accountable.
Transparency	Transparency must be fostered by providing the public with timely, accessible and accurate information.
Maximisation of human potential	Good human-resource management and career-development practices, to maximise human potential, must be cultivated.
Representativity	Public administration must be broadly representative of the South African people, with employment and personnel management practices based on ability, objectivity, fairness and the need to redress the imbalances of the past to achieve broad representation.

Table 3.3: Public administration values in South Africa's Constitution

3.3.6 A values-based analysis of HESTIIL

South Africa's value system revolves around putting the good of the people first. We employ measures that apply to the broader South African society to provide insights into HESTIIL performance. An assumption is made that the performance of the HESTIIL sector, in relation to values, will broadly be reflective of that of society as a whole.

One of the measures undertaken by government to support a strong ethical culture in South Africa is to introduce the Public Finance Management Act to guide conduct, particularly in relation to resources management. Further notable milestones in the promotion of ethical corporate conduct include the development of successive versions of the King Report on Corporate Governance. These are world-class publications that provide practical support to managers, at various levels, in relation to ethical conduct. In their 2019 report of the business ethics survey, conducted among listed companies, the Ethics Institute found that, on average, private organisations operating in South Africa fall within a moderate ethical culture risk category, represented by a score of 63 out of 100, where a higher number indicates a stronger ethical culture[64]. The survey results indicate that while some aspects of an ethical culture are present in South Africa's corporate sector, others remain underdeveloped. Out of the seven dimensions of the ethical survey, two were found to be particularly problematic: (a) a lack of ethical treatment of employees, and (b) a lack of ethics accountability and responsibility in

[64] The Ethics Institute. 2019. *South African Business Ethics Survey 2019*. The Ethics Institute: Pretoria.

organisations. The former has far-reaching implications for the analysis of HESTIIL and is further explored below.

Corruption is inimical to the achievement of the foundational values of South African society, namely human dignity, equality, freedom and the rule of law. Furthermore, corruption has a cancerous effect on all the public administration values. The odious presence of corruption has increasingly dominated public discourse in the last decade. The 2019 Corruption Perceptions Index, published by Transparency International, underlines the magnitude of the challenge for South Africa. The index ranks countries across the world according to their perceived levels of corruption, using a scale of 0 to 100, with 0 indicating 'highly corrupt' and 100 'very clean'. South Africa managed only a score of 44, which indicates that the country still grapples with a serious problem of corruption and its anti-corruption efforts appear to be ineffective[65].

The distressing hand of corruption has fastened its grip around both basic and higher education in South Africa. Corruption in higher education manifests itself in various forms. There have been reports of corruption in scholarly processes in the form of plagiarism, ghost-written assignments, student marks for money or sexual favours and even bribes paid for accreditation of academic programmes[66]. A plethora of other forms of unethical academic behaviours have also been confirmed by respondents within universities[67]. Even the incentive scheme introduced by government to promote research productivity by incentivising scholarly publication has raised the spectre of the so-called academic corruption[68]. The rest of the malfeasance that has been unearthed at higher education institutions is of a more familiar kind: a blatant and ravenous looting of public resources[69]. A recent report by an independent panel of assessors into one of the universities paints a grim picture of tender irregularities, unauthorised expenditure, unlawful HR practices and a litany of other forms of skulduggery[70]. All these malpractices were perpetuated and abetted by a culture of divisions, factionalism, rancour, vindictiveness, intimidation, fear, open hostility and downright thuggery – all of which are irreconcilable with an image of studious serenity that is normally associated with institutions of higher learning[71].

When institutional management and leadership systems have broken down, a university or research institution struggles to survive and can no longer fulfil its mission. Furthermore, it can no longer play its role within the institutional landscape. This brings about a general weakening of the entire system. In the case cited above, the university involved could not work effectively with a sister institution with which they shared facilities. While this led to major frustration on the part of students and lecturers on that campus, much more was lost in possible opportunities for collaboration that were squandered. In this case, the erosion of the value system in one public institution had immediate administrative consequences within that institution, and a debilitating influence in other parts of the HESTIIL. The scourge of corruption and unethical behaviour in public institutions is so serious that it has been

[65] Transparency International. 2020. *Corruption Perceptions Index 2019*. https://www.transparency.org/cpi2019.
[66] Sangonet Pulse. 2016. *Corruption in Higher Education*, 14 September 2016. www.ngopulse.org/event/2016/09/14/corruption-higher-education
[67] Mokubyane, P.H. 2015. *Public policy analysis of academic ethics and corruption in higher education with specific reference to universities in the Tshwane metropolitan area*. M.Tech dissertation. TUT. Unpublished.
[68] Jansen, J. 2020. Academic corruption rife at SA universities. *Daily Dispatch*, 2 February 2020. https://www.pressreader.com/south-africa/daily-dispatch/20200220/281900185230621
[69] Pityana, N.B. 2020. What is killing our universities? *City Press*, 20 February 2020. https://city-press.news24.com/Voices/what-is-killing-our-universities-20200220
[70] Higher Education Act (Act 101 of 1997 as amended). Report of the Independent Assessors into the Affairs of the Vaal University of Technology. Gazette No. 43015:127. 2020.
[71] Ibid.

placed before parliament[72]. Recently, the Minister of Higher Education, Science and Innovation bemoaned its effect in undermining the achievements that have been made[73].

Once corruption takes root within the public service, it has a debilitating effect on the entire value system. The efficient use of the public resources can no longer be possible. Greed and self-interest puts paid to the development-orientation. Instead of providing services impartially, fairly, equitably and without bias, corrupt individuals prefer those who aid and abet their shady dealings. Public participation is often the first casualty when unethical behaviour sets in. Where public participation cannot be avoided, it is conducted in a superficial and dishonest way, resulting in window-dressing, fronting and other forms of diversions. For example, the public may be called upon to nominate suitable board members for a public institution only for those submissions to be ignored in favour of politically connected individuals instead. This charade, apart from being costly in terms of time, money and effort, undermines public trust and weakens governance in public institutions. Public records are replete with instances of the above unethical conduct implicating a slew of state institutions.

The hallmarks of a "captured" institution are the lack of accountability and transparency. The public and the relevant watchdogs are fed sanitised reports that reek of obfuscation, diversion and creative accounting. These may lull unsuspecting stakeholders into a false of sense of satisfaction about the organisation's performance. When pointed questions are raised about the conduct or performance of the organisation, the coalition of the corrupt close ranks by feeding the public well-orchestrated red herrings, smokescreens and ad hominem arguments. Apart from the public that is ultimately robbed of the services it deserves, the first casualties in an organisation that is bereft of social values are often the honest and hardworking employees. And, they are often targeted for abuse and victimisation, through distorted human resources practices or other methods of harassment that are calculated to isolate, discredit or besmirch their character.

The new democratic order started on a strong ethical footing when the constitutional values were still fresh in the nation's conscience. These were epitomised by leaders within government that had an unimpeachable moral standing in society. However, as time went on, not even these strong foundations could withstand the corrosive effects of those who harboured selfish designs. The compounding effect of corruption during the course of the past ten years, was spectacularly laid bare in the 'state capture' report by the Public Protector in 2016 and more recently at the Zondo Commission of Inquiry into Allegations of State Capture. However, throughout the period preceding and following the state capture report, a steady stream of reports by the Auditor-General, court judgements and whistle-blowers had been giving clear indications of the rot that had established in both the public and private sectors. Regrettably, some of the institutions and organisations within HESTIIL have not been spared from embarrassment.

3.3.7 Some quantitative measurements

It is challenging to measure how well a country is doing in implementing its value system. However, it is advantageous to construct an illustration that is based on appropriate indicators. The public service values provided are more amenable to the use of proxies for this purpose. Drawing from various credible sources, both local and international, we generate a data set that gives an estimate of how South Africa fares based on a 10-point scale. A higher score indicates better performance in the value concerned.

[72] Parliament. 2018. *Universities tender fraud and corruption in the glare of parliamentarians*. https://www.parliament.gov.za/news/universities-tender-fraud-and-corruption-glare-parliamentarians
[73] *Eyewitness News*. 2020. Nzimande: Corruption still one of the biggest problems in higher education system. https://ewn.co.za/2020/01/24/nzimande-corruption-still-one-of-biggest-problems-in-higher-education-system

As a proxy for 'ethics', we use corruption as an indicator. For this purpose, the latest data available from Transparency International translates to a score of 4.4. For efficiency, we draw from the Auditor-General's latest report. The 2019 report makes for grim reading, indicating that the level of irregular, unauthorised or fruitless and wasteful expenditure within state institutions continues to worsen. Some of the HESTI institutions are among the listed worst offenders. The Auditor-General states that, out of the 383 public entities that were audited, only 100 (26%) could show they had used the money allocated to them ideally and for the intended purpose[74]. This gives a disappointing score of 2.6 for 'efficiency'. With a combined budget of over R347 billion for the 2018–2019 financial year, the state-owned enterprises (SOEs) play an important developmental role in South Africa's economy, including industrial development. Only 6% of the SOEs and their subsidiaries were found not to have serious breaches in management controls. If this is used as a proxy for 'accountability', it gives a score of 0.6.

According to the United Nations Development Programme (UNDP)[75], South Africa's human development index (HDI) has improved in recent years to a value of 0.705 in 2018. However, when the value is discounted for inequality, the HDI falls to 0.463. The 34.4% loss due to inequality illustrates the severity of the impact of inequality on the country. Flowing from these country statistics, 4.6 is assigned to 'development orientation' even though it could also be used as a proxy for 'impartiality, fairness and equity'. However, it is more compelling to argue that South Africa's development efforts address inequality more directly. The value of 7 provides a reasonable indication of performance in relation to 'maximisation of human capital'. When five of the eight public administration values are depicted on a graph, they provide a snapshot of how the country fares in relation to its value system as depicted in the accompanying figure.

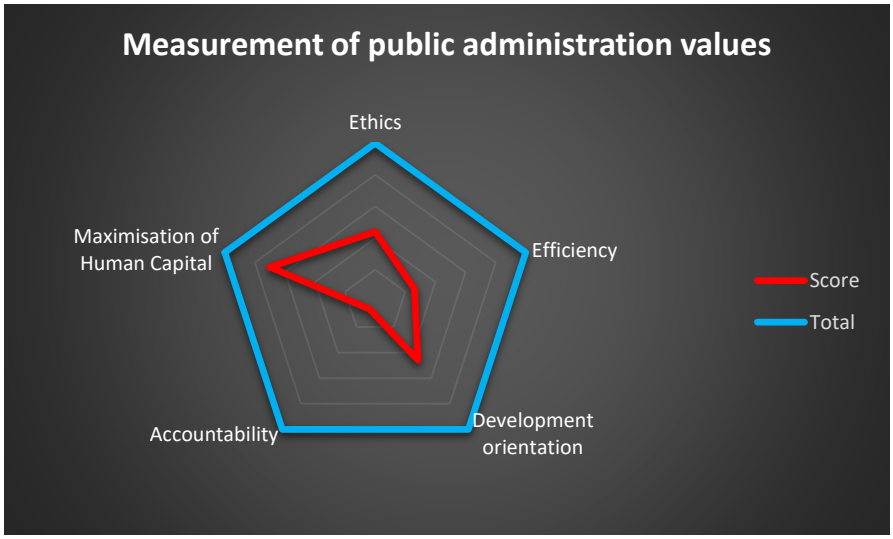

Figure 3.3: Measurement of public administration values

Except for performance related to the 'maximisation of human capital', the graph depicts poor performance across the board, with 'efficiency' and 'accountability' registering particularly poorly. The erosion of the country's value system, particularly in the public sector, has had a devastating effect on the capacity of the country to fulfil its development potential. Although the data used above do not

[74] Auditor-General of South Africa. 2019. *Citizens Report: 2018-2019*. Pretoria.
[75] UNDP. 2019. *Human Development Report 2019*. hdr.undp.org/sites/all/themes/hdr_theme/country-notes/ZAF.pdf

specifically address the HESTI system, the public entities that are key components of the NSI are heavily implicated in the above result.

3.3.8 Opportunities for a revival of values

Notwithstanding the deeply troubling findings discussed above - and sometimes because of them - beacons of hope have emerged. For the first time since the advent of democracy, a groundswell of opposition has developed against unethical conduct that cuts across the political, racial and other social divides that often lock individuals and groups into automated stratified responses to social issues. There has since been a renewed chorus for a rediscovery of social values. This perspective was also expressed robustly during stakeholder consultations held at the beginning of this review. There is renewed vigilance within society, particularly in relation to the conduct of public institutions. The government has consequently reviewed the powers and functions of some of the watchdog institutions as well as protocols to support whistle-blowers. And, a host of non-governmental organisations have emerged and enhanced their capacity to hold public representatives accountable.

All the above positive developments herald a new era of accountability and a renewal of constitutional values in South Africa. The new social compact – comprising government, independent organisations, the private sector and civil society – to combat corruption, provides real opportunities for a renewal of social values and a revival of nation-building. In this perspective, the attention given to inclusivity, sustainability and transformation by the White Paper on Science, Technology and Innovation as well at the White Paper on Higher Education and Training, bodes well for promoting coherence, collaboration and coordination within the HESTIIL.

A further dynamic that may prove to be an important opportunity in the cultivation of social values in future is the rise of values-based arguments for a range of social issues. For example, sustainable environmental values are emerging as a viable means of building consensus around decision-making regarding combating climate change. This may provide opportunities to demonstrate the powerful role social values can play in galvanising a common response to social challenges. In this perspective, therefore, a strong recommendation is made for the inculcation of constitutional values within the NSI, in order to create a common basis for nurturing coherence and collaboration in the quest for sustainability, inclusivity and social justice.

The COVID-19 global pandemic experienced in 2020 provides a shining example of how adversity can compel institutions and individuals to act in the interest of broader society rather than out of siloed departmental, institutional and selfish interest. When the number of infections and the concomitant fatalities rose across the world, the global community rallied around protecting human life at the expense of the economy, travel, sport, recreation and other human pursuits. This singular experience demonstrated - while sullied later by domestic corruption around the procurement of personal protective equipment and global vaccine nationalism - how a values-based response can rally humanity within and between nations toward the achievement of shared goals. South Africa and its HESTIIL can draw vital lessons on leadership, cooperation and coordination from this experience.

3.3.9 Entrepreneurship as a platform for inculcating new values

One of the parameters used by the Global Entrepreneurship Monitor (GEM) to measure the state of entrepreneurship in different countries across the world is “social value pertaining to entrepreneurship”[76]. As seen in the figure below, South Africa’s score in this indicator is a mediocre

[76] Global Entrepreneurship Monitor. 2019. *Is there a change in attitude towards the small and medium business in South Africa 2017/18*. https://www.gemconsortium.org/economy-profiles/south-africa.

4.4 out of 7, which places the country at 34th place out of 54 countries surveyed. South Africa is a perennial poor performer in most entrepreneurship surveys and consistently ranks at or near the bottom[77].

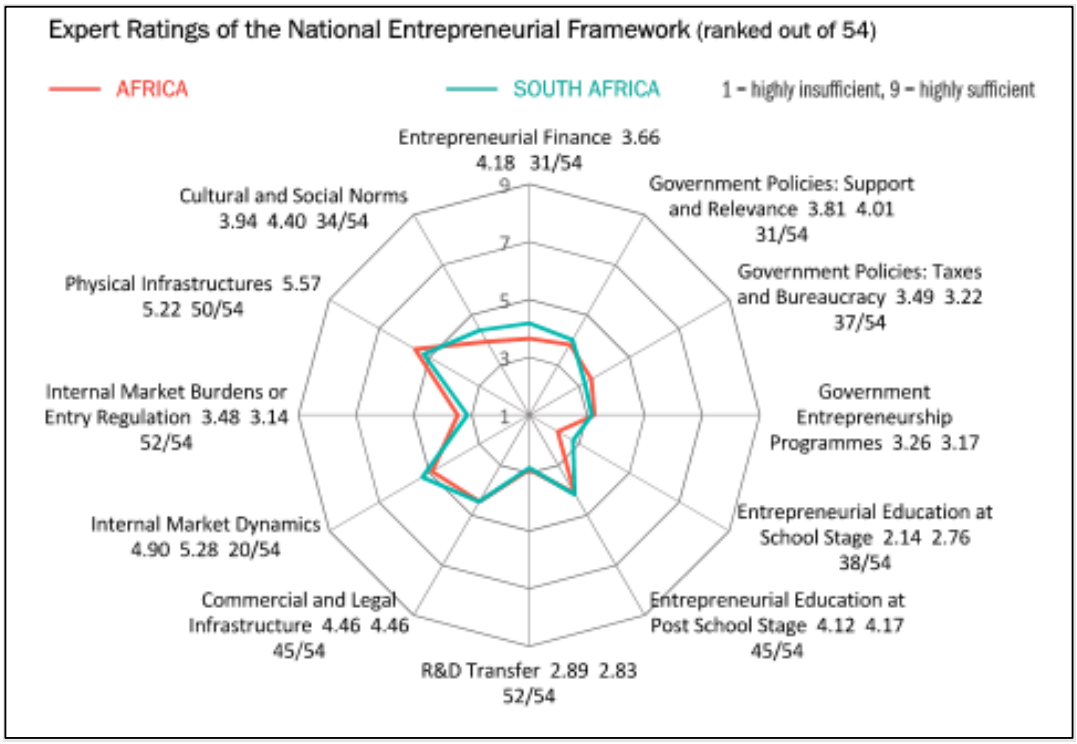

Figure 3.4: Expert Ratings of South Africa's Entrepreneurial Framework by GEM[78]

For a country that has one of the highest levels of unemployment in the world, the results might seem surprising. South Africa looks even worse when compared to its neighbouring countries, despite the more advanced physical infrastructure and other advantages that are lacking in most sub-Saharan countries. The lack of entrepreneurial spirit among the majority of South Africans boils down to a confluence of socio-cultural, political and historical factors that have shaped the general psyche and orientation of the country's populace towards entrepreneurship. This is also reflected in the country's value system which appears to favour, correctly so, the more abstract concepts, such as justice, dignity and freedom, as opposed to the more basic attributes necessary for survival. However, even this orientation is undergoing changing.

Young South Africans, particularly black South Africans, are beginning to acquire more positive perceptions of entrepreneurship[79]. This provides an opportunity for the development and inculcation of values that support entrepreneurship. The time has come for society, particularly the elderly, to disassociate the desire to embark on profit-making business ventures with negative connotations. The government has identified entrepreneurship as an important lever for socio-economic change.

[77] Luiz, J. & Mariotti, M. 2011. Entrepreneurship in an Emerging and Culturally Diverse Economy: A South African survey of perceptions. *S. Afr. J. Econ. Manag. Sci*. Vol.14 No.1, Pretoria, Jan 2011.
[78] Global Entrepreneurship Monitor. 2019. *Is there a change in attitude towards the small and medium business in South Africa 2017/18.* https://www.gemconsortium.org/economy-profiles/south-africa.
[79] Luiz, J. & Mariotti, M. 2011. Entrepreneurship in an Emerging and Culturally Diverse Economy: A South African survey of perceptions. *S. Afr. J. Econ. Manag. Sci*. Vol.14 No.1, Pretoria, Jan 2011.

Likewise, the drive to increase the rate of innovation, especially in the younger generation, should be accompanied by a concerted effort to shift the value system towards inculcating a business mindset.

Case study in entrepreneurship development: Sasol ChemCity

One of South Africa's iconic industrial companies, Sasol, made a singular contribution to entrepreneurship development. The Sasol ChemCity provides a valuable case study in entrepreneurship development in technology-based industries.

CASE STUDY 5: SASOL CHEMCITY

In 1955, Sasol established its first coal-to-liquid (CTL) production plant, which operated using a licensed technology from Germany called the Fischer-Tropsch process. Although CTL had been patented 25 years earlier, it had not been commercialised before. South Africa, through its newly established plant, was determined to make the technology work in order to achieve its ultimate goal of supplying a natural resource, low-grade coal and to develop a new industry that would reduce dependency on foreign supplies of crude oil while creating jobs and lower import bills. Like most new ventures, the initial phase of Sasol's first production plant experienced technical challenges. It was the first time that the new technology was used for commercial application and with South Africa pioneering this process, plant components such as gasifiers and reactors for producing hydrocarbon molecules had to be designed from scratch. Quite often during this phase, major technical challenges would be experienced which would threaten the entire production process. However, Sasol overcame the initial teething phase due to the strong skills capability developed by the organisation and its investment in research and development. Through these initiatives, the engineers and chemists were able to keep the plant operating efficiently. They were also able to diversify their value offering, which included feed stocks for the manufacture of synthetic rubber, fertilisers and secondary chemicals.

By the 1980s, Sasol was growing steadily. Their second CTL plant worth $2.8 billion was established in 1980 in response to the 1979 Middle East oil crisis, which had a negative impact on the world's oil supplies. Two years later, in 1982, the third CTL plant was built. The continual expansion of Sasol from 1955 to 1982 made research and development a priority. The in-house research and development capability led to the absorption and training of hundreds of science and engineering graduates who developed the necessary technical knowledge and research capability.

By 1999, Sasol had greatly diversified its value offering and was operating with even greater efficiency. Sasol Two and Three were producing chemical feedstocks and speciality chemicals while Sasol One was producing a wide range of chemicals such as acrylic acid, ethyl acetate and ethanol, among others. The diversification of their chemical product range gave Sasol a competitive edge and made them a pioneer of the petrochemical industry, both locally and globally.

With Sasol's success as Africa's chemical giant and government's view on the importance of public institutions contributing to the radical transformation of the economy, the Department of Trade and Industry (the DTI) and Sasol collaboratively made a R60-million investment towards the establishment of ChemCity, a 172-hectare eco-industrial park.

Objective: The principal motivation behind the establishment of ChemCity Eco-Industrial Park was the radical transformation of the South African economy. Sasol, as a public institution committed to this agenda, invested R41 million towards the project. The aim was to grow a generation of black industrialists that would participate in the manufacturing sector and ultimately contribute towards the growth of the South African economy.

Value proposal: The ChemCity project comprises four buildings designated for production and manufacturing activities, and a fifth for office-based and knowledge-intensive activities. Each of these facilities were specifically designed to suit the needs of start-ups and early-stage SMMEs in the chemicals, energy, agri-business, food-processing and manufacturing sectors. Additionally, the project aimed to provide support to new and existing BBBEE suppliers in business development, technology improvements and funding. This was a much-needed initiative to bolster the economic participation of black industrialists in the respective industries. Since inception, this dti and Sasol-sponsored project successfully established over 700 SMMEs which have created over 12 500 direct jobs.

Challenges and limitations: In 2014 Sasol discontinued ChemCity and developed a new enterprise-development system, which prioritises the insertion of black industrialists in its value chain. The information pertaining to the closure of ChemCity and the reports accounting for the initial investments by Sasol and the dti in 2012 and 2013 were not available for this review. Equally important to note is that despite the public and media announcements about the successes of ChemCity, no information is available about the initial recipients or beneficiaries. There are also no comprehensive records outlining the outcomes of the projects. Thus, we are unable to comment on the status of the 700 SMMEs which had participated in this ground-breaking development or present information on how many of them had succeeded or failed, nor the reasons for their success or failure. There is moreover no information available on the sectoral delineation of the focus of these SMMEs, or on the black industrialists and the sectors they have benefited from the revised procurement and training measures agreed upon by Sasol and the DTI We are also unable to comment on the impact of ChemCity on the Free State community. In this regard, it is recommended that the dti and Sasol undertake a study to determine the benefits derived from this ground-breaking project. This should ideally include a tracer study of a randomly selected group of beneficiaries.

Lessons:

- Although the ChemCity project had demonstrated some promise in the empowerment of black industrialists to become integral to the local and global supply chain systems, and thus to the broader ideal of economic development, the project has not continued as planned. Instead, elements of enterprise development have been integrated into Sasol's functions.

3.3.10 Application of values in policy and development

The opportunities for integrating values in HESTIIL management practice will create many benefits. They can be applied in ways so that they become a defining feature of HESTIIL. As an example of how values can be innovatively applied, they are demonstrated below in selecting catalytic areas of intervention in RDI. In this case, they serve as a component of the criteria for testing the suitability and robustness of the proposed RDI areas.

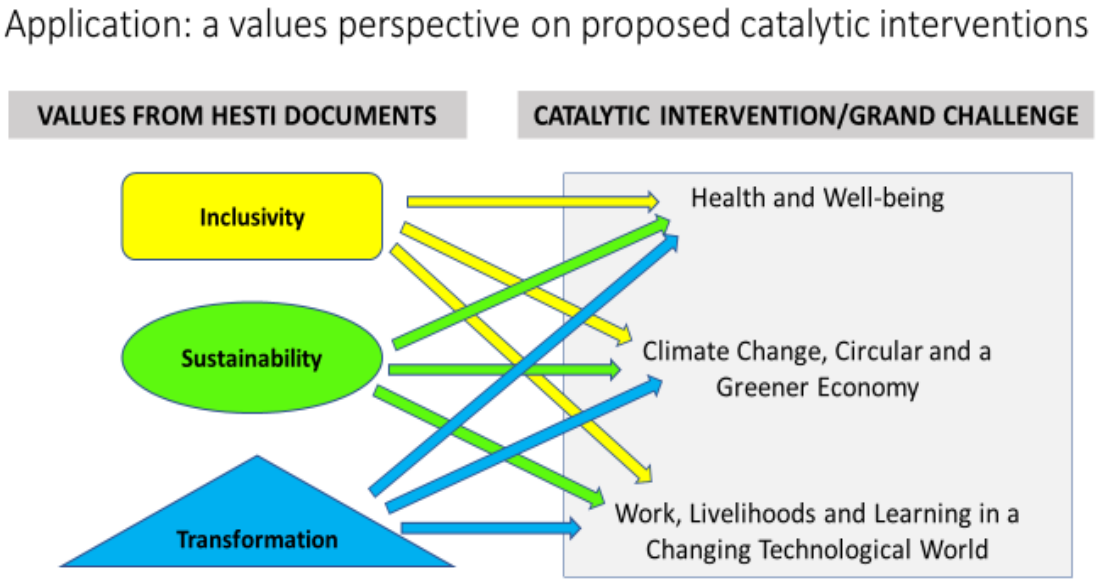

Figure 3.5: Application of values in selecting catalytic RDI interventions

In this example, the three values from the White Paper on STI were applied to various areas. In each case, we asked the question, "To what extent does the proposed RDI area help to realise each of the values?" In the above three cases, it was found that the listed areas provided ample opportunities for advancing each of the values, as illustrated by the connecting arrows in the accompanying figure. In this way, values can be used in combination with other criteria in strategic decision-making.

It can be argued that technological change constitutes a 'values' change because technology is informed by, and is an embodiment of, societal values. When a country has an ambition to develop its industrial output through technological innovation, its value system must accommodate the transformation. Japan is an excellent example of how a nation, steeped in ancient culture, managed to invoke its value system to assimilate, and eventually master, modern technologies. Since the Meiji Restoration of 1868, Japan began to systematically seek out and acquire the technological know-how that later transformed its economy into an industrial juggernaut by the end of the 20th century. The accompanying case study discusses how Japan managed to leverage her centuries-old value system to achieve this transition.

The lessons that can be learnt from Japan, or any other successful industrial economy, are important only as far as they take into account the different set of circumstances that apply to South Africa. The country's political economy is one of those contextual considerations.

3.4 Political economy

3.4.1 Definition and rationale

HESTIIL, and the NSI it is a part of, are subsystems of a wider political economy which is a part of the environment within which innovation occurs. There are factors within this environment which help or hinder innovation. The success of innovation is dependent on the capacity of the NSI to overcome the challenges and harness the opportunities presented by the environment. The more the environment is supportive of innovation, the higher the prospects of innovation. To a large extent, the environment in which innovation occurs is shaped by the political reality around it. For this reason, innovation policy needs to take account of the political economy of the country. Political economy analysis therefore is a necessary aspect of a HESTIIL review and is critical for establishing viable mechanisms to bring about a more coherent and collaborative innovation system.

Political economy analysis is concerned with examining the various forces that shape market power within the NSI. It looks into the interaction of political and economic processes within a society and the processes that create, sustain and transform these relationships over time. Innovation is the deployment of new value in society which may be commercial or social. Even when an innovation has no direct commercial value, to the extent to which it contributes to the well-being of society, that innovation has a discernible economic dimension and therefore it is the subject of economic analysis. The distribution of benefits from economic activity which derives from innovation tends to be neglected in policy analysis. This is a serious omission because innovation, particularly in industry, is driven by an expectation of deriving exclusive benefits from the investment made and the risks taken in the conduct of such innovation.

As indicated above, the kind of innovation that takes place within an economy, and the extent to which it takes place, are dependent on the degree to which the political economy is supportive of innovation. An innovation system is a finely balanced system of policies, institutions and organisations that are concerned with bringing new value to the economy. Innovation policy therefore is concerned with shifting the balance within the innovation system so that it favours increased investments and risk-taking in innovation. Expectations about the return on investment in innovation are uppermost in the minds of innovators. The 'rules of the game' regarding the rewards of innovation are very much within the remit of politics which renders political economy analysis indispensable in innovation policy analysis. In order to understand the drivers of innovation activity within an economy, it is essential to explore the patterns of distribution of economic value that derives from innovation. In political economy analysis such an analysis, which is often neglected in traditional innovation policy analysis, takes centre-stage.

3.4.2 Macro-economic policy

Since the advent of democracy, the main driver of South Africa's economic policy is to address poverty, inequality and unemployment. Various good intentioned but unsuccessful efforts have been made in order to elevate the economy onto a higher growth path. The resultant sluggish economic growth has helped to keep the level of unemployment high for an extended period. This has constrained the government's ability to implement its developmental objectives which include improving education outcomes, increasing the levels of skills, providing better healthcare, promoting innovation and reversing de-industrialisation. The failure of the economy to absorb a high number of unemployed people has caused the government to significantly lift levels of social spending as a poverty alleviation measure.

South Africa has a population of over 59 million people that is characterised by a high dependency ratio, owing to the high unemployment rate and a younger demographic profile. Although the population growth rate has more than halved since 1994, it has continued to remain above 1% in the past five years, pointing to a stabilisation of the current socio-economic challenges. The impact of the COVID-19 pandemic on the economy will likely add further weight to the already daunting challenge of reducing poverty, unemployment and inequality.

Since 1994, the ANC-led government has developed a succession of economic policies aimed at addressing the country's largest social challenges, namely poverty, unemployment and inequality. Some of these policies include:

- Reconstruction and Development Programme (RDP) – 1994
- Growth, Employment and Redistribution (GEAR) – 1996
- Accelerated Shared Growth Initiative of South Africa (ASGISA) – 2006
- New Growth Path – 2012
- National Development Plan (NDP) – 2012

The macroeconomic policy history of South Africa represents the various states of resolution of an ongoing tussle between developmental and market or competition approaches. The developmental approaches favour a state-led, more interventionist approach to economic policy in a bid to address the country's challenges head-on. The focus of building a competition state, on the other hand, is on strengthening the economy in such a way that social dividends will ultimately derive from the resulting economic growth. While all the policies accommodate both perspectives, the RDP is often regarded as representative of a developmental approach, whereas GEAR leans more towards a market or neoliberal approach. All in all, South Africa's macroeconomic policy is characterised by the ongoing convergence and divergence between developmental and market approaches[80].

The macroeconomic policy dynamics have far-reaching implications for innovation in the country. It can be argued that the demise of technological development megaprojects in South Africa's recent history, such as the Joule and the PBMR, have more to do with the dynamics of macroeconomic policy than anything else. While the government makes every effort to balance the various interests that are vested in economic policy, the ideological tug-of-war might be contributing to creating an unstable and uncertain climate for innovation[81]. The uncertainty could be particularly unfavourable for investment in risk-bearing ventures such as technology start-ups and other innovation ventures.

The environment for innovation is sensitive to the broader macroeconomic policy. It is imperative for innovation policies and programmes to be responsive to, and take account of the prevailing economic policy. The ideological contestation that manifests in macroeconomic policy is not the only contention that prevails in South Africa's political economy. Other polar tendencies shape and skew the innovation landscape, pulling it in opposite directions. We discuss a few polar tendencies that have direct implications for innovation policy.

3.4.3 Polar tendencies

Although the economic policy of the country is clearly defined, the political economy of South Africa manifests some contestation as evidenced in several dichotomies in the goals and actions of some key

[80] Thomson, P. & Wissink, H. 2018. Recalibrating South Africa's Economy: Challenges in building a developmental and competitive state. *African Studies Quarterly*, Vol. 18 (1), September 2018.
[81] Ibid.

actors. These polar tendencies have become more pronounced as the euphoria and moral influence of the democratic change recede into the past.

3.4.3.1 Innovation vs rent-seeking

Two concepts that are often misunderstood in economics are innovation and rent-seeking. If the two concepts are understood precisely, there ought to be a dynamic and exclusionary relationship between innovation and rent-seeking. This is because innovation stands in contradistinction to rent-seeking.

Rent-seeking is described as socially wasteful competition through which an individual, group or firm seeks to increase their own wealth without creating any benefits to society[82]. Rent-seekers embark on activities that are calculated to deliver financial gain, monopoly or power to them without improving productivity[83]. Based on these definitions, rent-seeking is therefore diametrically opposite to innovation. Rent-seeking is detrimental to the economy because it skews the distribution of benefits such that they are inequitably shared in society. In this perspective, the ultimate social consequences of rent-seeking can be horrendous, which can include an increase in inequality and unemployment, as illustrated in the examples cited below.

Rent-seeking behaviour can take on different forms and dimensions. Racism was a form of rent-seeking in that race-based laws were used to exclude black people from economic activities such as vocational and professional occupations, education and land ownership in order to generate rents for the dominant group[84]. Similarly, party rent-seeking occurs when political parties penetrate and control the state to use public offices for their own advantage, as opposed to the general public good, through party patronage, party clientelism and corruption[85]. Party patronage[86] and party clientelism[87], on the one hand, are forms of exchange relationships between patrons and clients in which state resources, such as jobs and contracts in government and other state institutions, are traded for political support. Corruption, on the other hand, entails undermining established decision-making procedures through private arrangements that often involve illicit exchanges[88].

Innovation and rent-seeking are two forces that pull in different directions in a political economy. A political economy that is heavily influenced by rent-seeking can discourage innovation. There are other opposing tendencies at work within South Africa's political economy.

3.4.3.2 People vs profit

A mixed economy bestows freedom on individuals and groups to embark on activities that are designed to maximise profits. The Constitution allows private citizens to engage in an endless list of economic enterprises including mining, consumer goods, agriculture and a whole range of services. As

[82] Brooks, M. A. & Heudra, B. J. 1989. An Exploration of Rent Seeking. *Economic Record*, 65(1), 32–50. doi:10.1111/j.1475-4932.1989.tb00676.
[83] Bhagwati, J.N. & Srinivasan, T.N. 1982. The Welfare Consequences of Directly Unproductive Profit-seeking (DUP) Lobbying Activities: Price versus quantity distortions. *Journal of Int. Economics*, 13 August, pp 33–44.
[84] Roback, J. 1989. Racism as Rent Seeking. *Economic Inquiry*, Vol. XXVII, October 1989, 661481.
[85] Van Biezen, I. & Kopecky, P. 2007. The State and the Parties: Public funding, public regulation and rent-seeking in contemporary democracies. *Party Politics*, Vol 13. No.2, pp. 235–254.
[86] Müller, W. C. 2000. Patronage by National Governments. In: Jean Blondel and Maurizio Cotta (eds) *The Nature of Party Government. A Comparative European Perspective*, pp. 141–60. Basingstoke: Palgrave.
[87] Müller, W. C. 2000. Patronage by National Governments. In: Jean Blondel, and Maurizio Cotta (eds) *The Nature of Party Government. A Comparative European Perspective*, pp. 141–60. Basingstoke: Palgrave.
[88] Van Biezen, I. & Kopecky, P. 2007. The State and the Parties: Public funding, public regulation and rent-seeking in contemporary democracies. *Party Politics*, Vol 13. No.2, pp. 235–254.

long as activities are conducted within the law, the profit motive can be pursued regardless of any impact it may have on people. Innovation in this context can be exploited for the enrichment of a few at the expense of the collective good through intellectual property protection and other mechanisms.

The government has provided incentives for private enterprise to balance the profit motive with more people-centric endeavours, among other things, through corporate social investment (CSI). The total CSI expenditure in 2019 is estimated at R10.2 billion, much of it going to various areas of need that are meant to alleviate poverty and inequality[89]. At 50%, education-related projects receive the lion's share of CSI. This support could be regarded as indicative of the willingness of the private sector to lend support in addressing the economic inequality that continues to plague the country. Nevertheless, critics have labelled CSI programmes as cosmetic, grudging and masking the historical culpability of the private sector in apartheid[90]. The level of CSI has flattened in the past five years, in real terms, coinciding with a diminishing business confidence in the economy.

Notwithstanding the best intentions of CSI, the profit motive remains inimical to endeavours that put people before profits. Within the NSI, public sector entities are expected to partner with the private sector to achieve developmental objectives. The ultimate policy imperative for STI is an inclusive and sustainable development which presupposes cooperation with the private sector, among other partners. However, the disparate motives of the private sector appear to have been sparsely accommodated in policy, particularly the 2019 White Paper. There is a need to address the fundamental question: What is the basis for cooperation in innovation policy among NSI partners that have variant interests?

3.4.3.3 Growing the economy vs radical economic transformation

It is necessary to reflect on the latest manifestation of policy contestation in South Africa's political economy landscape. Since the beginning of 2017, the term 'radical economic transformation' (RET) has assumed a particular import in the nation's political lexicon and generated intense debate in the country's economic discourse and body politic.

Since the advent of democracy, it had been assumed that all economic policies of government, including Broad-Based Black Economic Empowerment (BBBEE), were variously intended to transform the historical patterns of ownership in the country. However, owing to growing frustrations about the slow pace of transformation, there has been a growing call for more radical measures. The term 'radical economic transformation' came to prominence after President Jacob Zuma delivered the ANC's January 8 anniversary statement at the Orlando Stadium in 2017 and has since set the cat among the pigeons in public political discourse. Since then, RET has become a rallying call for those who seek more radical measures on the part of the government in addressing poverty, unemployment and inequality.

The pillars of the RET perspective seem to be spearheaded by the call for expropriation of land without compensation. In addition, government is called upon to nationalise some of the productive sectors of the economy, including the mining and financial sectors, and to invigorate township and rural economies. These and other proposed RET measures are meant to loosen the strong grip of the so-called 'White Monopoly Capital' on the levers of the country's wealth.

[89] Trialogue. 2019. *Business in Society Handbook 2019*. https://trialogue.co.za/publications/2019-business-in-society-handbook-flipbook/

[90] Fig, D. 2005. Manufacturing Amnesia: Corporate social responsibility in South Africa. *International Affairs*, 81(3), 599-617.

RET has been vehemently opposed by the private sector and other influential individuals and formations. They have been dismissed as, at best, a dangerous rhetoric that reflects the factional divisions within the ruling party, and at worst, a licence for further looting of the state by the ruling elite. Instead, those who dismiss RET have responded with a diametrical opposite set of interventions that will ostensibly achieve the objectives of reducing unemployment, inequality and poverty. These measures, designed to accelerate economic growth, include: 'labour market reform, reconceptualising black empowerment away from elite enrichment, and stripping away burdensome business regulations'[91].

The point of this discourse is not to get enmeshed in the various controversies, but to point out how they bifurcate the economic discourse in the country, particularly in relation to addressing the most pressing socioeconomic challenges. The foregoing illustrates the widening rather than narrowing gap between influential camps as the scale of the challenges increases. As indicated above, some of the public institutions are caught in the vortex of the contestation as they attempt to navigate the sometimes churlish wrangling. In the midst of these multipolar contestations, STI policies are caught between the horns of a dilemma, or ought to be, as tectonic shifts play out in the country's economic landscape. A key challenge is, how can all the sectors of society within the NSI be brought together behind the new STI goals?

The Review Panel maintains that it is no longer tenable for STI policy to eschew these dynamics in the economic landscape, particularly in view of the quest for inclusive innovation.

3.4.4 Identifying anchor points for a shared NSI worldview

Without cooperation within the NSI, there is little prospect that the objectives of the White Paper on STI, in particular, would ever be realised. In this perspective, the stakes are high for identifying the common bases for bringing about increased coordination, coherence and partnering among the economic actors in the country. Political policy analysis is important for providing the necessary strategic insights required to formulate a basis for partnership between the public and private sectors in particular.

The proposed approach to the political economy goes beyond a mere tick-box exercise that only acknowledges the socioeconomic history and lists economic data that are relevant to innovation. It advocates an in-depth discussion of a real-world political economy that is grounded in specific cultural, social and historical details. It encourages a genuine discourse among partners with a view to co-developing a common purpose behind STI outcomes. This approach discounts any attempts to take for granted the desired commitment of partners but seeks to invest in a rigorous analysis of interests that can serve as anchor points for genuine cooperation.

Private participation in the development and implementation of innovation policy is not a trivial. It is economic activity that generates the resources required to sustain a chain reaction of market activities that propagate the benefits of innovation in society. Moreover, whilst this kind of political analysis might lead to a certain innovation activity prospering, this success in itself can generate a political constituency with an interest in maintaining the economic activity, because of a sizeable number of people that would continue to benefit from it. This would trigger a virtuous circle towards the emergence of a knowledge economy that would serve the developmental and economic goals for all involved. This presents a significant opportunity for a positive realignment of interests within the HESTIIL.

[91] Centre for Development and Enterprise. 2017. *Radical Economic Transformation*. CDE: Johannesburg.

At face value, rent-seeking and the profit motive are at odds with policy imperatives that promote innovation and people-centredness. Nevertheless, as long as rent-seeking and profiteering are conducted within the law, they are perfectly acceptable as part of enterprise in a democratic state. It is well within their rights for industries to choose to be technological laggards if that works for their business models. As long as freedom permits it, individuals and organisations will pursue varied and sometimes contradictory activities. In the interest of a coherent NSI, the onus is on the policymakers to convince partners, the private sector in particular, to pull in the same direction. Polar tendencies can be reconciled by a meticulous examination of common interests and values. The points of intersection of our human needs provide leverage points for consensus building among all stakeholders within the NSI.

3.4.5 Interorganisational networks within South Africa's political economy

Our analysis of the country's political economy will not be complete without a look at the interorganisational networks that exert an influence within South Africa's economy. The phenomenon of interorganisational networks is important for understanding the powers behind the ideological contestations and polar tendencies discussed above as well as others.

Interorganisational networks have the following characteristics[92]:

- Consist of several distinguishable organisations.
- Have a significant amount of interaction with each other.
- Include extensive, reciprocal exchanges of resources or intense hostility and conflict.
- May be linked directly or indirectly.
- May consist of a series of organisations linked by multiple and direct ties to each other.
- Characterised by a clustering of linkages around one or a few mediating or controlling organisations.
- Employ various strategies to protect their interests.

Understanding the insidious influence of interorganisational networks in the economy is critical as they wield more power than is often apparent and consequently skew the balance of influence within the NSI. Within South Africa's political economy, there are active networks both within and between the private sector and organised politics. Some of these networks serve as the selectorate in the political sphere as well as in other roles of influence, such as boards of listed companies, SOEs and the supposedly independent watchdog institutions. From a critical theory perspective, it is unthinkable for STI policy to attempt to rally the NSI into collective action without a rigorous analysis of the power dynamics at play within the system. The interorganisational networks have sufficient influence to completely undermine HESTI policies if these threaten their interests.

3.4.6 Financial outflows

Another feature of the political economy that has been ignored in STI policies is that of financial outflows. In recent years, the issue of financial outflows out of Africa, both legal and illicit, has received increased attention. A lion's share of the financial outflows takes place from South Africa, which has a long history of this phenomenon. Prior to 1994, the protracted period of political instability gave rise to conditions that encouraged capital flight[93]. Strikingly, after the democratic change, when there was

[92] Benson, J.K. 1975. The Interorganizational Network as a Political Economy. *Administrative Science Quarterly*, Vol. 20, No. 2 (Jun. 1975), pp. 229–249.
[93] Fedderke, J. & Liu, W. 2002. Modelling the determinants of capital flows and capital flight: with an application to South African data from 1960 to 1995, *Economic Modelling*, 19, pp. 419–444.

a much more stable political and economic climate, the magnitude of capital flight increased. A closer look at the figures suggest that the scale of the problem is staggering.

Firstly, looking at illicit financial outflows, Global Financial Integrity (GFI) estimates that the country lost $37 billion during the period between 2010 and 2014[94]. This is in addition to the more than $100 billion that was lost between 2002 and 2011, which suggests that the problem continues unabated. These are unrecorded private financial outflows used by residents to accumulate foreign assets in contravention of applicable capital controls and regulatory frameworks. These transactions generally involve capital that is illegally earned, transferred or utilised. The most significant component of illicit outflows is deliberate mispricing that constitutes misinvoicing of international trade transactions with the ultimate purpose of concealing and diverting financial resources to offshore accounts. The misinvoicing can be done during the exportation or importation of goods or services. The data indicates that the top five categories for potential revenue loss include commodities (machinery, electrical machinery and vehicles) that are among the most commonly imported goods into South Africa[95].

According to GFI, the practice of trade misinvoicing has become normalised in many categories of international trade whereas it is a major contributor to poverty, inequality and insecurity[96]. The social cost that derives from these illicit financial outflows undermines sustainable growth in living standards and exacerbates inequities and social divisions, issues which are critical in South Africa today.

Capital flight is defined as "a residual of the Balance of Payments consisting of discrepancies between recorded foreign exchange inflows and recorded uses of these inflows"[97]. Capital flight constitutes an outflow of financial resources from a country within a given period that are not recorded in official government statistics. Capital flight therefore is narrower than the illicit financial flows, which include flows that may be recorded but are illicit. The cumulative amount lost from South Africa owing to capital flight from 1980 to 1993 was an average of 5.4% of GDP per year, and this figure grew to an average of 9.2% of GDP per year from 1994 to 2000[98]. While the definitions of capital flight vary and the measurements are subject to debate, the general upward trend of this phenomenon is of serious concern to this situational analysis.

The sustained high levels of capital outflow have debilitating effects on development as they drain the country of the necessary resources to drive the economy. According to the GFI, capital flight "drains an economy through weakening the value of a country's currency, hurting the domestic banking sector, undermining public investment and the ability of governments to increase real GDP"[99].

The continuous flow of funds out of the country, even during periods of policy certainty and economic growth, suggests a deep-seated distrust on the part of local capital of the country's trajectory. This brings into question the status of the 'social compacts' between government and the private sector, in particular. More pertinently to this review, capital flight has been empirically found to have an

[94] Global Financial Integrity. 2019. *South Africa, Revisited: Trade Misinvoicing and Lost Revenue in 2016*. https://gfintegrity.org/south-africa-revisited-trade-misinvoicing-and-lost-revenue-in-2016/
[95] Ibid.
[96] Ibid.
[97] Ndikumana, L. & Boyce, J.K. 2018. *Capital Flight from Africa: Updated methodology and new estimates*. Political Economy Research Institute (PERI), University of Massachusetts: Amherst
[98] Mohamed, S. & Kinoff, K. 2004. *Capital Flight from South Africa, 1980-2004*. Forum paper, African Development and Poverty Reduction: The macro-micro linkage. 13-15 October 2004, Lord Charles Hotel, Somerset West, South Africa.
[99] GFI. 2019. *Out of Africa: Capital flight*, 26 August 2019. https://gfintegrity.org/out-of-africa-capital-flight/

adverse effect on industrialisation[100]. Innovation is sensitive to investment; innovation-led industrialisation can only take place when there is a sustained resource commitment and a willingness to take risks in support of untested local economic opportunities. When assets and capital are shifted offshore, seemingly on a whim, it does not bode well for local innovation. Furthermore, the high level of capital flight does little to build confidence on the part of foreign investors in the local economy.

One of the pillars of STI policy is the growth of gross investments in R&D to reach a level of at least 1.5% of GDP by 2030. This goal can only be achieved when government and the private sector commit to making sustained investments in local RDI in the next 10 years. However, the staggering outflow of capital cast doubts over the achievement of this goal. Given that the economic impacts of R&D are dependent on the achievement of the appropriate levels of investment, the ramifications of capital flight spells disaster for the prospects of inclusive growth and poverty alleviation. To put the above numbers into perspective: every year, South Africa loses about 10 times the current Gross Expenditure on R&D (GERD) to capital flight. This is something that cannot be ignored in this discussion when the full commitment of the business sector to the goals of the NSI is so vital.

The effect of the divestment of the business sector in the local economy is made manifest in the declining proportions of contributions to R&D by the business sector. The following table, computed from the 2017/2018 Statistical Report of the South African National Survey of Research and Experimental Development, shows a steady decline of the proportion of Business Expenditure on R&D (BERD) in the GERD between 2008 and 2018. The percentages of BERD to GERD are computed from the 2017/18 figures of the national R&D survey conducted by the Centre for Science, Technology and Innovation Indicators (CeStII).[101]

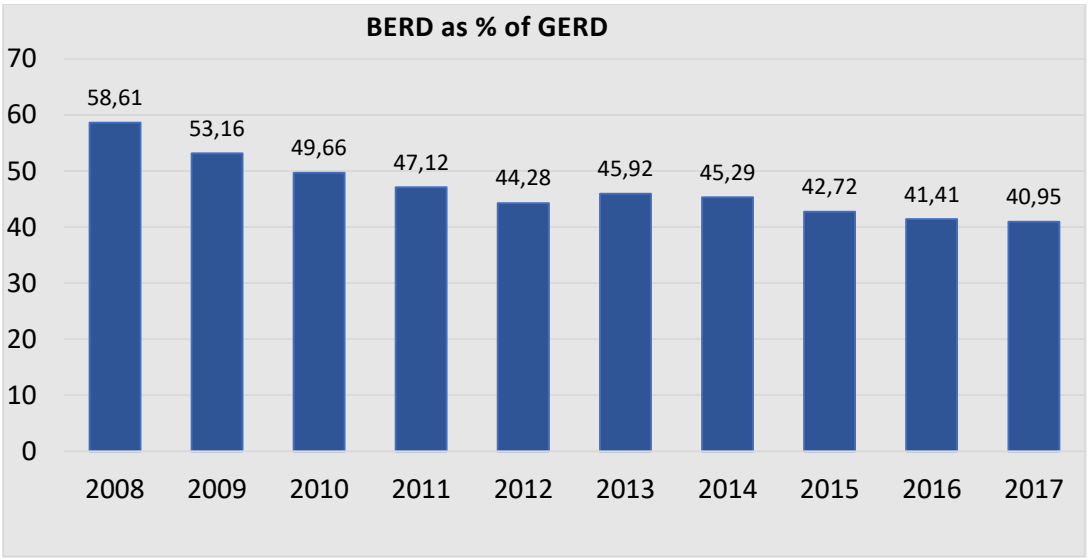

Figure 3.6: BERD as % of GERD between 2008 and 2018

The percentage of BERD to GERD in 2008 was close to 60%. In the following ten years, the proportion of BERD has diminished to close to 40%. This is a massive decline which calls for scrutiny by the

[100] Asongu, S.A. & Odhiambo, N.M. 2019. Governance, Capital Flight and Industrialisation in Africa. *Economic Structures 8*, 36 (2019). https://doi.org/10.1186/s40008-019-0170-2.
[101] CeSTII. 2019. *South African National Survey of Research and Experimental Development: Statistical Report: 2017/18*. HSRC: Pretoria.

relevant sectoral leaders within the NSI. This decline comes at a sensitive time when new policies and plans are being put together for STI. There is a need to ask searching questions about the implications of the effective divestment of business from local R&D.

When the expenditures are expressed in constant 2010 Rand values, the collapse of the BERD, both in absolute terms and relative to the other sectoral contributions, becomes starker.

YEAR	GERD	GOVERNMENT	SCIENCE COUNCILS	HIGHER EDUCATION	BUSINESS	NOT-FOR-PROFIT
	R'000	R'000	R'000	R'000	R'000	R'000
2008/09	24 056 681	1 303 016	3 586 992	4 792 079	14 099 455	275 139
2009/10	22 285 515	1 135 087	3 677 697	5 425 204	11 846 693	200 833
2010/11	20 253 802	1 011 340	3 596 022	5 424 601	10 059 009	162 830
2011/12	20 847 389	1 159 901	3 500 987	6 203 958	9 822 399	160 144
2012/13	21 283 167	1 281 658	3 589 510	6 538 113	9 424 677	449 209
2013/14	21 551 944	1 425 413	3 615 334	6 125 162	9 896 243	489 792
2014/15	23 351 132	1 506 354	3 982 443	6 666 417	10 576 214	619 704
2015/16	24 478 150	1 523 812	4 345 732	7 476 385	10 457 645	674 575
2016/17	25 304 686	1 487 844	4 350 273	8 265 881	10 479 245	721 444
2017/18	25 962 839	1 559 379	4 232 771	8 722 451	10 632 765	815 473

Table 3.4: R&D expenditure by sector, constant 2010 Rand values (2008 to 2018)

The contribution of the business sector decreases from over R14 billion to less than R10 billion in less than three years, before recovering marginally to stabilise at just over R10 billion in the last four years of the available data. This represents a decline of close to 25% over the ten-year period, based on the constant 2010 Rand values. As can be seen from the table, business is the only sector to have recorded a decline on this basis.

When the BERD is broken down into its components to reveal precisely where the money is spent, the results produce more cause for concern. According to the latest R&D survey report[102], the largest contributor to BERD since 2011/12 is the financial intermediation, real estate and business services sector, whose contribution to BERD was 48.8%. The manufacturing sector's contribution to BERD in 2017/18 was only 28.2%, down from a high of 38.8% in 2009/10. Bearing in mind that industrial development in the manufacturing sector is a key economic policy objective for the country, this trend in the breakdown of BERD is alarming in its own right.

How does South Africa's BERD, as a proportion of total BERD, compare to some of the leading economies in the world? In Table 3.7, generated from 2017 OECD figures, South Africa is compared to a selection of countries, both within and outside the OECD.

The data demonstrates that in the leading knowledge and industrial economies such as Japan, Korea, Germany and Switzerland, the large proportion of R&D expenditure is funded by the private sector. Typically, in these economies, over 70% of R&D funds come from the private sector.

[102] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.

For most other leading economies, the percentage of GERD financed by business exceeds 50%. The OECD average is above 60%. Hovering around the 40%-mark, South Africa is an outlier with a negative outlook. With the future trajectory firmly pointing in the downward direction, taking the country away from the norm in the leading industrial economies, there is an urgent need to redress this trend.

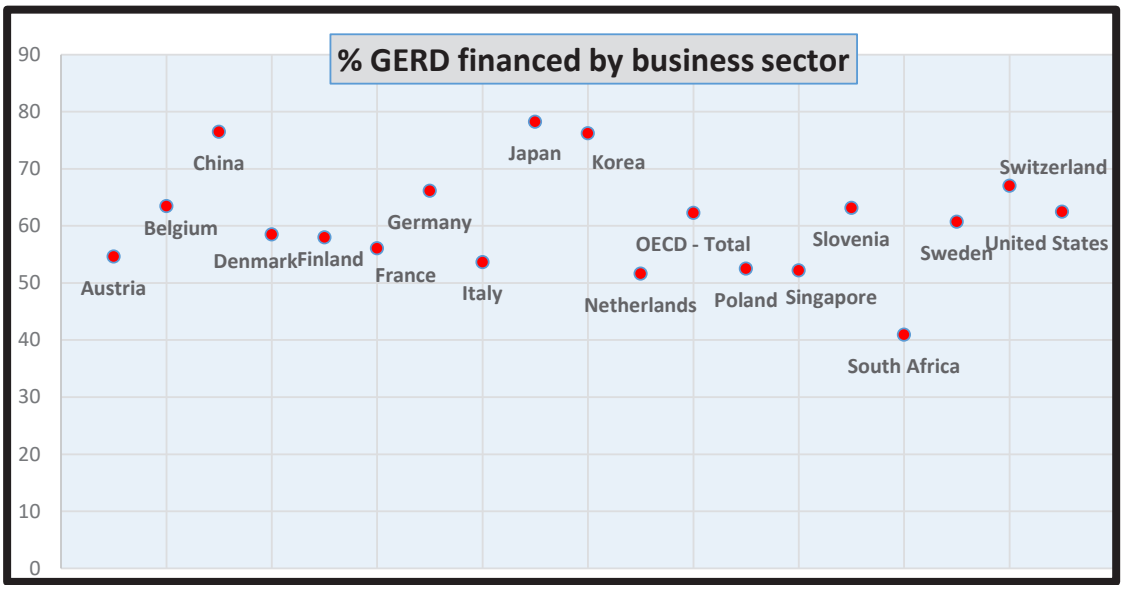

Figure 3.7: Percentage of GERD financed by the business sector (2017 values from OECD data[103])

Private sector funding for R&D is important for more than simply increasing the resource base for technological innovation in an economy. It plays a unique catalytic role that is crucial for realising a range of RDI outputs. In an empirical study conducted among 20 countries (18 OECD and non-OECD), it was found that[104]:

- Government-financed GERD (GOVERD) and **BERD** have a strong impact on patent applications.
- HERD and **BERD** positively influence technology receipts.
- **BERD** and the percentage of GERD financed from abroad (FERD) have a significantly positive influence on technology payments.
- **BERD** and HERD have a strong positive influence on total FTE researchers.
- The number of publications positively depends on HERD and GOVERD.

As highlighted in the above findings, BERD has the highest catalytic impact compared to all other sources. The accompanying figure serves to illuminate this impact.

[103] OECD. 2020. *Main Science and Technology Indicators*. https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB# (accessed 22 May 2020)
[104] Aruzhan, S., Alzhanova, F., Alibekova, G., Tleppayev, A. & Medeni, T. 2016. Econometric evidence of the effectiveness of different R&D funding sources. *International Journal of Economic Perspectives* 10. Pp 317–330.

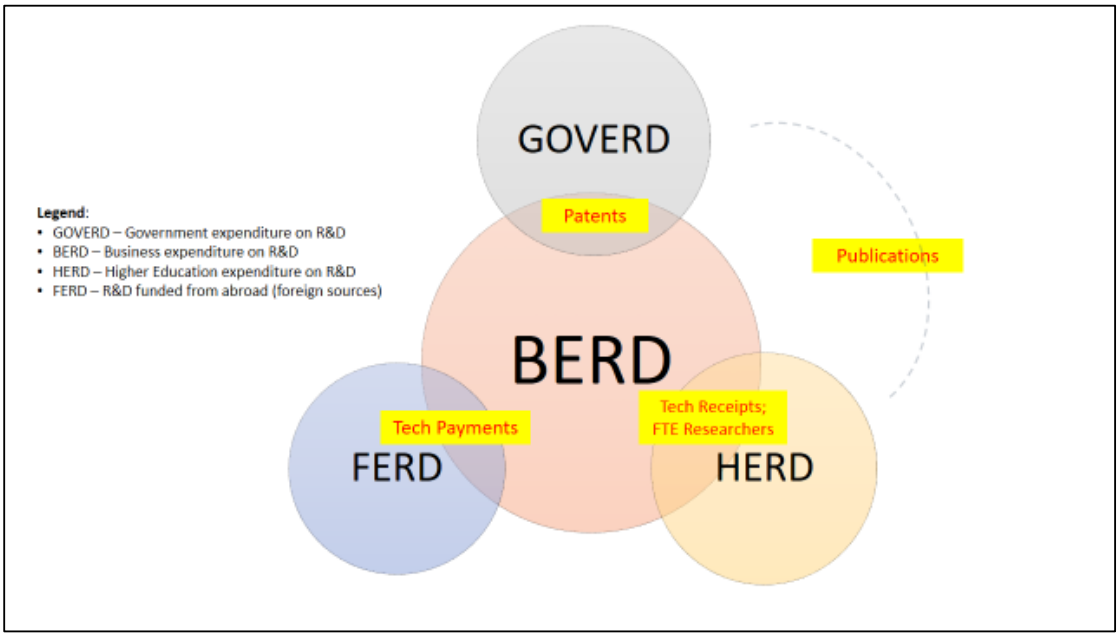

Figure 3.8: Catalytic effect of BERD on key R&D outputs

Working in conjunction with other sources of funding, BERD was found to have a direct positive influence on the realisation of a number of outputs, namely patents, publications, technology payments, technology receipts and FTE researcher equivalents. This suggests a unique importance of BERD in the NSI. The number of publications does not appear to be influenced by BERD. The critical importance of BERD seems to be on the indicators that have a direct bearing on innovation and economic performance. This analysis provides ample food for thought for South Africa's evolving HESTIIL.

3.4.7 Towards a post-COVID-19 political economy

The country's needs with respect to a political economy that supports a coherent and collaborative HESTIIL that can give effect to inclusive growth, sustainability and transformation are clear.

- Innovation policies need to take the intricacies of the local political economy into account in order to navigate and leverage the polar tendencies that are prevalent within both the private and public sectors. A failure to recognise and accommodate these driving forces within the country's political economy, including the power dynamics and interorganisational networks involved, will undermine the achievement of inclusive innovation and a transformed economy.

- Ongoing and vigilant political economy analysis is critical for nurturing a coherent and collaborative HESTIIL. The relevant government departments should regularly take stock of the dynamics in the political economy and respond accordingly to ensure the integrity of the NSI as a coherent and synergistic whole.

- The SWOT analysis reveals key forces that have direct implications for HESTIIL. These include tendencies and practices that are inimical to innovation and a people-centric policy regime. These tendencies are found in both the private and public sectors and can be invoked to explain some of the lost opportunities in technological innovation.

- There are strong opportunities to design the future in a manner that will not only navigate, but also leverage, the defining influences within the country's political economy. Conversations with the private sector should be aimed at identifying anchor points for a shared worldview in order to incorporate the best of all worlds without sacrificing focus and autonomy.

- The issue of capital flight should be redressed, using all the opportunities and means at the government's disposal; equally so the diminishing proportion of BERD in the GERD. Studies should be undertaken to explore the most appropriate mix of funding sources, taking the need for increased GERD, the dynamics of the local economy and the lessons from other comparable economies into account.

3.3 Systems

The basis for this systems analysis is the quest for an improved HESTI landscape that ensures that the country's institutional capacity is well-equipped to deliver an integrated and coordinated NSI.

3.3.1 Background and conceptual underpinnings

In the context of a newly established democratic order, the NSI conceptual framework was introduced by the 1996 White Paper on Science and Technology to provide structure and purpose within the country's knowledge and technology environment. The NSI conceptual framework has succeeded in organising policy-making and the monitoring and evaluation of knowledge-based activity in the country. However, this has been inadequate in some important respects, as discussed in the next section. Since 1996, there has been further evolution in thinking about how innovation works between institutions which also needs to be taken into account.

The 1996 White Paper provided a denotative meaning of the NSI as a "set of functioning institutions, organisations, and policies that interact constructively in the pursuit of a common set of social and economic goals and objectives". However, since then people have ascribed connotative meanings to the term so much so that a mere reference to South Africa's NSI often evokes disparate emotions, ranging from those who deny its existence to those who swear by it. It is necessary to establish a common conceptual foundation to such a central term as a prerequisite to a meaningful discourse.

References to the 'national system of innovation' or national innovation system (i.e., NSI or NIS) in South African STI policy have at least three aspects to its meaning:

- There is an aspirational aspect in the use of the term in that it points to a desired reality. This is why the NSI is such a powerful policy construct in that it can immediately conjure up a state that most patriotic people can desire for the country.

- However, the NSI concept also bears elements of grounded realism in that there are observable institutions, organisations, policies and other structures that seemingly interact towards achieving common goals. This is the actual or real NSI that exists in a current, albeit dynamic, form and is described by a variety of indicators such as those used in R&D and innovation surveys. In this ontological sense, therefore, the NSI has an empirical basis, notwithstanding the various opinions about its state of function.

- A third way in which the NSI construct is used is an evolutionary one which is characterised by an ongoing search for the best way of achieving the aspirational NSI. When reference is made

to the application of policy imperatives to shift the existing NSI to the ideal, a transitory state of 'a becoming NSI' is evoked.

In the normal discourse relating to the NSI, there may be subtle shifts in the meaning or emphasis between these three conceptions. If these shifts in meaning and nuance take place undetected, they can cause confusion.

Subsection 3.2.1 of the STI-WP provides an example for the above. In the first paragraph of this text, titled 'Inclusion', NSI is used in an aspirational sense, i.e., as a conceptual framework, depicted in the apex of the accompanying diagram.

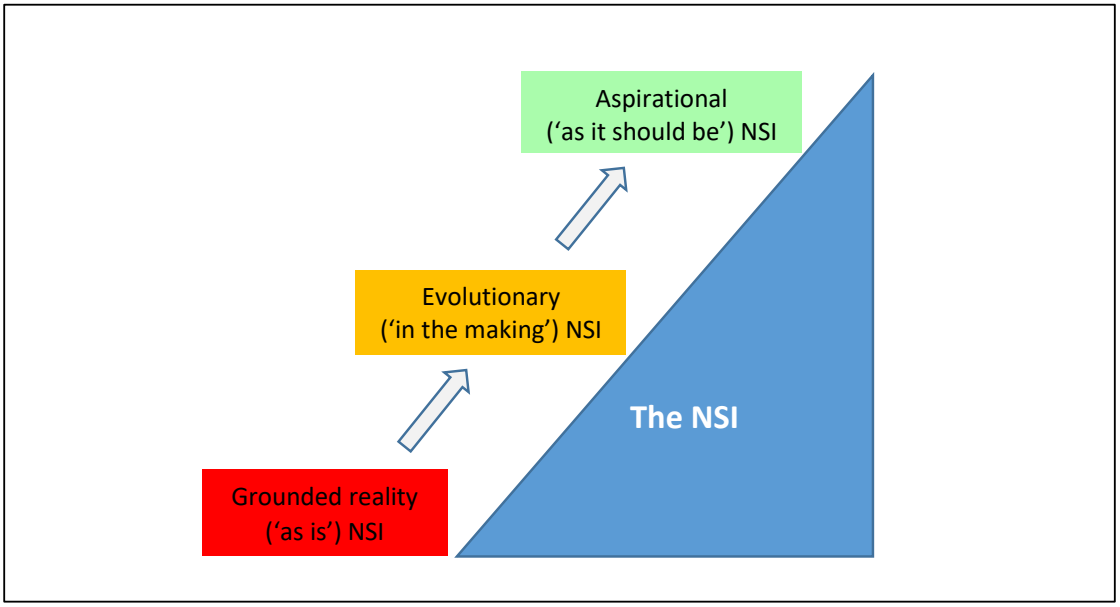

Figure 3.9: Illustration of three conceptions of the NSI

In the second paragraph of this subsection, reference is made to civil society serving as potential link within the NSI. In both instances, NSI is used in a transitive sense to denote a system that is becoming or changing into something else. The use of the word 'potential' lends a hint to the evolutionary 'in-the-making' NSI that is being referred to. The inclusive NSI referred to in the third paragraph goes back to the aspirational or idealised NSI. In the remainder of the subsection, referring to gender representation, the meaning shifts to the NSI as a real 'as is' entity.

The STI-WP retains the NSI as a conceptual framework for the innovation process in South Africa. This is a positive move in that the NSI approach allows for a more realistic conceptualisation of the innovation enterprise. In the past there has been an almost exclusive framing of innovation as science-based and technology-driven, which is prone to representation as a linear process. It is perhaps understandable for a public entity that is responsible for promoting science and technology to drive technology-driven innovation. However, innovation can also derive from other forms of human activity, as has been demonstrated before[105], and this should be accommodated in the overarching policy.

[105] Manzini, S. T. 2015. Measurement of innovation in South Africa: An analysis of survey metrics and recommendations. *SAJS*, Vol 111 No 11/12 (2015): https://doi.org/10.17159/sajs.2015/20140163

A grave fallacy of the linear model of innovation is that an increase in scientific output will necessarily increase the rate of innovation. This correlation is disproved by the accompanying table that shows that the country journal publication output more than doubled between 2005 and 2016, while the patent output – used as a proxy for innovation – remained moribund. This linear outlook regarding scientific output tends to perpetuate a proclivity for 'technology-push' approaches to STI policies, programmes and incentives. The inevitable outcome of such an approach is the marginalisation of the private sector and an unhealthy dominance of government-centred efforts that fail to ignite innovation-based entrepreneurship and industrialisation. It is hoped that the reaffirmation of the NSI framework as a fundamental policy posture, as well as the renaming of DST to DSI, will help promote a systems approach to innovation and a re-ordering of innovation policies, programmes and instruments to reflect the complexity of knowledge flows that drive technical change within the economy.

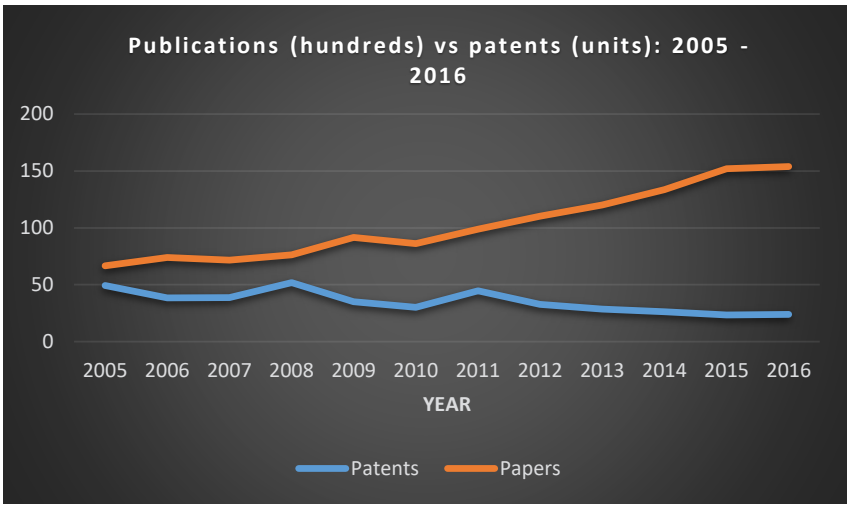

Figure 3.10: Publication output[106] [107] (in hundreds) and Triadic patents[108] from 2005 to 2016

3.3.2 Issues regarding the NSI as a systemic whole

Definitions of an innovation system generally include the following four elements: actors, networks, institutions and knowledge or material artefacts. Much effort in the past has focused on actors and less so on networks and institutions. More recently, as illustrated in the STI-WP, increasing attention has been given to networks, i.e., the linkages, communication and other processes that bring together different actors in advancing innovation. This is an encouraging shift in addressing problems regarding lack of coordination.

Elsewhere in this report, attention is given to the review of actors in the NSI, particularly the need to vastly upscale their number and size. Actors are the various organisations that perform different but connected functions in driving innovation. The main actors in the innovation value chain include government, firms, SOEs, science councils and universities. The foregoing discussion, in regard to the

[106] Academy of Science of South Africa (ASSAf). 2019. *Twelve Years Later: Second ASSAf Report on Research Publishing In and From South Africa (2018)*. [Online] Available at: DOI:10.17159/assaf.2018/0030.
[107] DHET. 2019. *Report on the Evaluation of the 2017 Universities' Research Output*. Pretoria.
[108] OECD. 2020. *Triadic Patent Families (indicator)*. doi: 10.1787/6a8d10f4-en (Accessed on 24 May 2020).

political economy, outlines some of the attendant constraints. Apart from the number and size, consideration is also given to optimising the configuration of the various actors around identified RDI areas as appropriate.

Networks, which refer to the links established between separate actors to perform a diverse range of tasks, including learning, knowledge creation and diffusion, are discussed below. A key requirement for the development of an innovation-driven economy calls for new structures of interaction and collaboration. As argued above, the business sector is the key actor in innovation-based industrial development. The seemingly diminishing role of business as funder and performer of research within the South African economy in recent years is a cause for concern.

This review places a great deal of attention on institutions, which include those intangible aspects that define the country's innovation context such as norms, values, power structures and the political economy. Attention to institutions is called for because it enriches the NSI discourse by "reducing uncertainty by providing information; managing conflicts and promoting cooperation; and providing incentives for innovation"[109]. Many of the pertinent issues are reviewed in the analysis of the political economy.

3.3.3 The STI-WP on improving the functioning of the NSI as a system

The 2019 White Paper on Science, Technology and Innovation identifies several issues related to improving the functioning of the NSI for policy intervention. By and large, the issues that have been identified for attention in the next wave of the NSI development process are valid. The planned responses are mostly appropriate, while some require intense scrutiny.

3.3.3.1 Inclusiveness

One of the limitations of South Africa's innovation policy since 1994 has been confusion about how to integrate the fight against poverty in STI plans, and to contribute towards addressing the challenges of inequality and unemployment. Efforts have swung between poverty alleviation science and technology missions on one hand, and the promotion of cutting-edge innovation to drive industrial development that would ultimately lead to trickle-down socio-economic benefits, on the other. None of these measures have thus far yielded the desired effect. On this basis, poor and marginalised people remain shut out of the innovation discourse and have little to appreciate from the investments that have been made into science and technology since 1994. This calls for a rethinking of innovation policy and a reconceptualisation of the NSI to better position itself for addressing poverty, unemployment and inequality.

The recalibration of innovation policy in the 2019 White Paper on Science, Technology and Innovation to incorporate inclusive innovation provides a platform for a reimagining of the NSI. However, every effort should be made to avoid shaping HESTIIL and the NSI as means to inadvertently worsen inequality. The quest articulated in the STI-WP for inclusivity, sustainability and transformation should trump all conceptualisations of our knowledge and innovation systems in order to shift the interests of the poor from the periphery toward the focal point of innovation plans and programmes.

From the outset, the policy intent speaks to the need for inclusivity and proposes the integration of civil society in the NSI; as well as increasing the number of women and black participants at various levels of the system. While these measures have their own merits, on their own they do not constitute

[109] NACI. 2016. *Situational Analysis: Innovation Theory, Practice and South African Context*. Pretoria.

inclusiveness. Before addressing the merits of bringing in more partners to participate in the NSI, it is necessary to examine the conceptualisation of inclusivity.

As discussed above, the idea of positioning the NSI for inclusivity is a noble one. However, the conceptualisation of inclusive innovation in the STI-WP falls short in some key respects. It lacks the foundation of a rigorous analysis in the issues that motivate for inclusivity. Owing to this shortcoming, the measures that are being identified for bringing about inclusivity are inadequate.

Since 1996, innovation policy in South Africa has been mainly about shifting the economy towards the production of knowledge-intensive consumer goods and services, particularly in the formal economy. On the face of it, the NSI was not conceived and configured to directly address poverty, inequality and the survival needs of the low-income majority of the population. Except for a few specific 'poverty alleviation' programmes, the bulk of the policy instruments do not substantively promote the participation of poor, unemployed or otherwise economically marginalised people in the townships and rural villages, in order to help them develop and deliver innovative technologies that would stimulate their economic development. To be sure, there have always been instruments earmarked for the inclusion of the poor, but these approaches constitute an inadequate conception of inclusive innovation. Inclusive innovation is different from conventional views of innovation:

> *"Conventional views of innovation (often implicitly) understand development as generalised economic growth. By contrast, inclusive innovation explicitly conceives development in terms of active inclusion of those who are excluded from the mainstream of development. Differing in its foundational view of development, inclusive innovation therefore refers to the inclusion within some aspect of innovation of groups who are currently marginalised."*[110]

Inclusive innovation needs to be inclusive both substantively and procedurally: substantively, in the sense that it addresses the root problems of the disenfranchised in a sustainable way; procedurally, in that the process grants the "rights, voice, capabilities and incentives for the excluded to become active participants in processes of development and innovation"[111]. There are many other pertinent considerations, but this hopefully sketches the broad contours of what constitutes inclusive innovation. From the foregoing, it is clear that the conceptualisation of inclusive innovation in the White Paper should be improved in order to discourse the dismantling of the underlying structures of the economy that are responsible for creating and sustaining exclusion.

Returning to the merits of extending participation, allowing formerly marginalised groups to participate could project an image of diversity at a superficial level, without transforming the agenda and the power dynamics that are at play within the organisations in the system. There is a difference between diversity and inclusiveness. Inclusiveness is about creating a tradition and culture in which all people feel valued and respected and have access to the same opportunities. A much more profound conceptualisation of inclusive innovation and a clearer agenda for inclusivity in the NSI are necessary. This could be carried out as a dedicated study, perhaps under the auspices of NACI. Notwithstanding the identified shortcomings, the articulation of the inclusive innovation as a policy imperative provides the platform for a more meaningful and comprehensive engagement of the subject. The conceptual outlines of inclusive innovation that is pertinent to South Africa's NSI, including a more elaborate discussion of the gaps in the current policies, is found at **Annexure D**.

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[110] Foster, C. & Heeks, R.B. 2013. Conceptualising inclusive innovation: modifying systems of innovation frameworks to understand diffusion of new technology to low-income consumers, *European Journal of Development Research*, 25(3), 333-355.

[111] Johnson, B. & Andersen, A.D. 2012. *Learning, Innovation and Inclusive Development*, Aalborg University Press, Aalborg, Denmark.

With regard to diversity, although the demographic profile within the NSI has changed substantially since 1994, in many organisations women and black people continue to be marginalised in subliminal, subtle, or sometimes blatant ways[112]. This is because these institutions remain culturally untransformed. The experience is that marginalised groups are mainly included to fulfil employment equity requirements. Their qualifications and expertise are often subjected to unfair scrutiny and sometimes even with disdain. In many organisations there is no appreciation of the diversity of experiences and worldviews that women and black people can contribute to those organisations. As a result, these groups are often subjected to patronising references as 'BEE' or 'transformation' employees. When the dominant members or cliques are not sensitised to and embrace the need for inclusivity, those "included" feel disempowered, leading to resentment and alienation. This often manifests in backlash and complaints about 'reverse discrimination'. We address this and other related issues in the analytical dimension dealing with people.

3.3.3.2 Linkages, networks and partnerships

Linkages are the lifeblood of an innovation system. Various studies in different contexts demonstrate that multidimensional collaborations between actors in an innovation system improve innovation performance[113]. The whole concept of the NSI is premised on the assumption that progress occurs when the various actors in the system establish and maintain a network of mutually reinforcing relationships that translate knowledge into innovation, resulting in improved economic performance.

Successive reviews have pointed out various aspects of the fragmentation of South Africa's NSI. The 2007 OECD review reported weak linkages between national policy on one hand, and the provincial and local spheres, on the other[114]. The 2012 Ministerial Committee Review Report highlighted the lack of horizontal and vertical coherence and integration, which manifested in conflicting sector R&D programmes and a poor conceptualisation of the role of business, large and small, within the NSI[115]. The 2017 STIL1 Report ascribed the dwindling support of research by business on "(i) poor intra- and intergovernmental cooperation and coordination, (ii) the lack of systemic NSI coherence between government, higher education, and civil society, and (iii) the deep-seated gap between business and government.[116]" The above reviews made recommendations to address the respective findings on fragmentation, which continues to be a serious concern.

Undoubtedly, there are weaknesses in relation to linkages and partnerships in the NSI. However, it is important to clarify issues so that the crux of the problem can be better understood by all. Some of the above reviews appear to conflate NSI governance with the RDI networking that should characterise the innovation process, as discussed earlier. For the sake of clarity, we first deal with the latter point here.

There are several deficiencies in the NSI that give rise to and perpetuate the lack of linkages among NSI partners. These include:

- Lack of clarity about the meaning of and need for collaboration;
- Structural, socio-cultural and personal limitations;

[112] Khunou, G., Phaswana, E., Khoza-Shangase, K. & Canham, H. (eds). 2019. *Black Academic Voices: The South African Experience*. HSRC: Pretoria.
[113] OECD. 1991. *National Innovation Systems*. http://www.oecd.org/science/inno/2101733.pdf.
[114] OECD. 2007. *OECD Reviews of National Policy: South Africa*. https://dx.doi.org/10.1787/9789264038240-en
[115] DST. 2012. *Department of Science and Technology Ministerial Review Committee on the Science, Technology and Innovation Landscape in South Africa*. Pretoria.
[116] DST. 2017. *Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape*. Pretoria.

- Innovation excluded in existing collaborations; and
- Poor articulation between national policy and regional initiatives.

We address each of the above issues to shed light on the weaknesses that afflict the NSI and to possibly identify opportunities and leverage points to fulfil the policy intent of the White Paper of increased coordination and integration.

(i) The meaning and role of collaboration within the NSI

Collaborations between actors in the NSI was identified as the most important attribute of the system and a critical success factor. The most effective way of producing innovation involves network interactions of firms with other firms, research institutes and other organisations[117]. As organisations continue to co-develop and produce innovations within the economy, the capacity of the various actors is enhanced through technological learning, resulting ultimately in a sustainable ecosystem of actors and a knowledge economy.

For a term that is so central in the NSI conceptual framework, 'collaboration' does not have an exact or commonly understood definition[118]. This is a recipe for confusion as the term 'collaboration' might denote completely different things to different people. To address this problem, a common definition of collaboration has been proffered as, "the process of formal and informal negotiations between autonomous actors, during which they create common rules and organizations to regulate their interactions and fields of activity, or tackle common issues cohesively, with these common rules shared by all stakeholders, while negotiations are taking place continually"[119].

The essence of the above definition is that mutually engaged actors, when they collaborate, share information, resources, responsibilities and risks to jointly plan, implement and coordinate mutually beneficial activities. Defined in this way, collaboration is a deeper kind of relationship that is distinct from networking and cooperation as depicted in Figure 3.11 below.

From the figure, it is evident that collaboration, in the context of co-creating shared outputs within the NSI, constitutes a deeper level of interaction and interactive communication. Furthermore, collaboration is predicated on free will on the part of the actors. They need to identify a reason for entering into collaborative arrangements with other entities. To this extent, collaborations cannot be forced through legislation or other means. However, government can create conditions that encourage NSI partners to collaborate, using incentives among other inducements.

Government, through DSI and DTIC instruments, has provided incentives to foster collaboration and other means of cooperation. Some of the incentives that have been implemented in the past include the R&D Tax Incentive Scheme, the Sector Innovation Fund and the Support Programme for Industrial Innovation. However, these instruments do not seem to have fully achieved their goals, which raises the question, what else should the government do?

[117] Powell, W.W. & Grodal, S. 2005. Networks of innovators. In: Fagerberg, J., Mowery, D.C.,Nelson, R.R. (Eds.), *The Oxford Handbook of Innovation*. Oxford University Press, Oxford, pp. 56–85.
[118] Russell, M.G. & Smorodinskaya, N.V. 2018. Leveraging Complexity for Ecosystemic Innovation. *Technological Forecasting & Social Change* 136 (2018) 114–131. https://doi.org/10.1016/j.techfore.2017.11.024.
[119] Thomson, A.M. & Perry, J.L. 2006. Collaboration processes: inside the black box. *Public Adm. Rev.* 66 (s1), 20–32. http://dx.doi.org/10.1111/j.1540-6210.2006.00663.x.

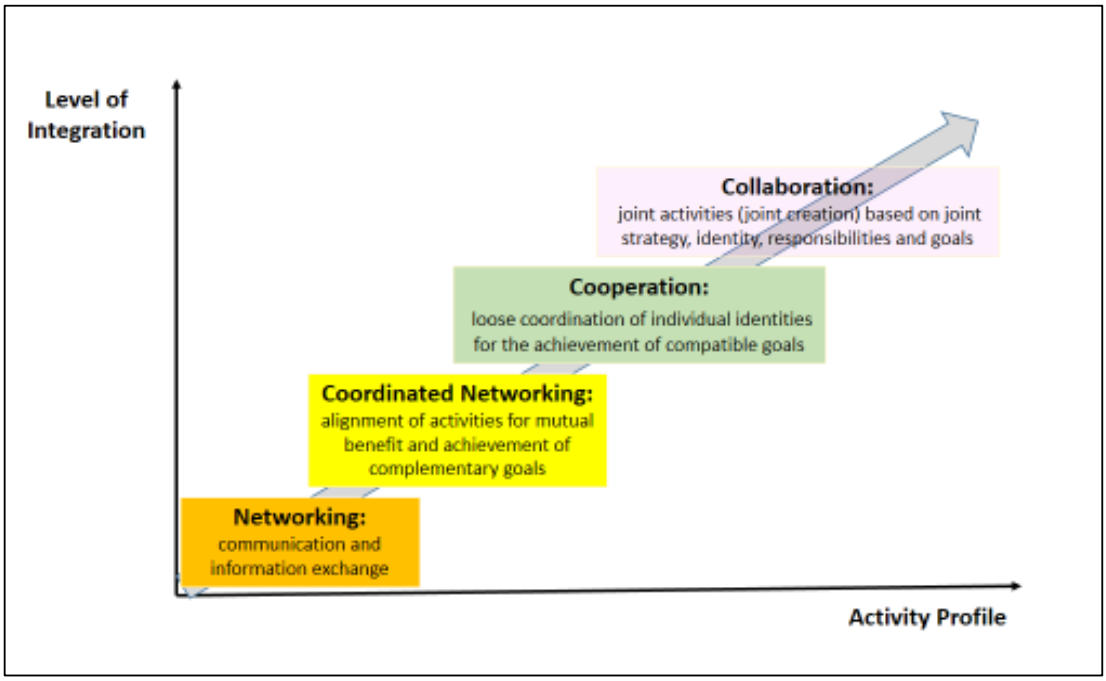

Figure 3.11: Growing levels of interactions from networking to collaboration
(adapted from Russell, et al.[120])

When instruments like these fail to deliver the necessary results, more direct and interventionist actions by government are called for, bearing in mind the socio-economic challenges facing the country. In the 2016 Situational Analysis developed by NACI, a call was made for the state to "act decisively to strengthen capacity building within firms, entrench institutions to facilitate the functioning of markets (such as competition), promote the development of productive networks and introduce specialisation patterns which generate processes of structural change"[121].

(ii) Structural, socio-cultural and personal limitations

Although the above definition of collaboration serves to highlight the intensity of linkages between NSI actors, it does not preclude other levels of relationships. The levels of integration may change back and forth, in any order, depending on the dynamics of the interactions.

Given South Africa's political economy, there are other impediments that prevent NSI actors from building linkages and networks for innovation. Some have to do with the structural stratification that has historical roots that go back to the apartheid era. There are organisations that are physically secluded or governed by security protocols that limit ready access to outsiders. Some of the submissions made by sector leaders cited the PFMA as a significant impediment to some forms of exchange and partnership.

[120] [120] Russell, M.G. & Smorodinskaya, N.V. 2018. Leveraging Complexity for Ecosystemic Innovation. *Technological Forecasting & Social Change* 136 (2018) 114–131. https://doi.org/10.1016/j.techfore.2017.11.024.
[121] NACI. 2016. *Situational Analysis: Innovation Theory, Practice and South African Context*. Pretoria.

Within some universities and public research institutions, a culture of non-cooperation persists. Units operate as silos, with unhealthy competition as the dominant mode of operation. Although rivalry is part of human nature, when it gets out of control to the extent that it defeats the overall goals of the organisation, the intervention of management is called for. Plenty of research supports the idea that competition and cooperation can go hand in hand in academic research[122] and in industrial innovation[123]. In this respect, the policy intent for open science and innovation, as outlined in the White Paper, is appropriate.

Ultimately, all collaborations constitute person-to-person engagements. Owing to personal dispositions and personalities, some people are naturally inhibited to social interaction. These factors need to be considered when appointing people to certain positions in order to ensure that the group dynamics within relevant echelons do not militate against institutional relationship-building. When the responsible leaders lack the skills, or the interest, to generate the necessary relationships within the NSI, personal limitations may translate to institutional opportunity costs. In such a case, the appropriate people-management interventions need to be activated.

(iii) Innovation excluded in existing collaborations

During a roundtable discussion with sector leaders at the beginning of this Review, a representative of an industrial sector indicated that interactions between private sector organisations, including SOEs and other relevant institutions, did take place as a matter of course. However, these interactions were not focused on innovation. In this instance, they were meant to address shared concerns about productivity in that sector.

This example gives rise to considerations that need to be factored into this discourse. Firstly, interactions, or even collaborations, that may seem to be absent from the perspective of innovation, may be taking place in other guises. This is good and proper because it is predicated upon shared needs. Where it can be identified that technology or innovation can play a role, e.g., in improving productivity, there is an opportunity to use the existing platforms to extend the relationships to include innovation activities. It is not necessary for collaborations for innovation to be developed from scratch.

Secondly, in this instance, we learnt that the industrial partnership came about out of the needs of the entities in that sector. It did not include the public institutions that are responsible for technology and innovation. This suggests that, at the very least, extensive effort should go towards information sharing about the role of innovation in addressing a variety of industrial challenges. When industrial players come together to address any sector challenges, and there is a role for a knowledge-based solution, prior awareness of the available support will facilitate a reaching out to the appropriate institutions in the STI sector. It is more desirable for the relationships to be built voluntarily, based on real needs, than to attempt to force them.

Lastly, some individuals, businesses and industrial firms and sectors could be technological laggards by choice. This may be a bitter pill to swallow from a STI perspective, but it is a fact of life. There may be rational reasons why some people and firms stick to existing technologies, including inertia, fear, satisfaction with what they have, loyalty, simplicity or even nostalgia. These are all very human emotions, choices and dispositions. Ultimately, technology is all about enhancing human experiences. If people are content with what they have, there is no point in forcing them into a change that they

[122] van den Besselaar, P., Hemlin, S. & van der Weijden, I. 2012. Collaboration and Competition in Research. *High Educ Policy* **25,** 263–266 (2012). https://doi.org/10.1057/hep.2012.16.
[123] Baldwin, C.Y., von Hippel, E. 2011. Modeling a paradigm shift: from producer innovation to user and open collaborative innovation. *Organ. Sci.* 22 (6), 1399–1417. https://doi.org/10.1287/orsc.1100.0618.

are not yet ready for. The late adopters are entitled to stick to the technologies they have, for whatever reason, as long as they are aware of the available options and what these can do for them.

(iv) Articulation between national, provincial and local spheres

As indicated above, in reference to the 2007 OECD review, there is poor articulation between national innovation policies and the initiatives at provincial and local levels. Despite a few sporadic initiatives to address this policy lacuna, this has remained a weakness in our system ever since, as observed in this statement in section 4.9 of the 2019 White Paper:

> *"Historically speaking, STI policy has mostly focused on R&D, perpetuating a system that has not optimally contributed to improving local economies. Furthermore, innovation-support institutions remain concentrated in the major metropolitan areas."*

The new initiatives outlined in the 2019 White Paper that are aimed at developing local innovation systems warrant some examination in this perspective. Some of the initiatives that have been proposed include providing support for local and grassroots innovators so that they can be integrated into local economic development planning, as well as establishing more technology incubation centres. Much of the detail required to fully assess the significance of the policy intent is yet to unfold. Nevertheless, the whole new thrust in policy towards addressing spatial marginalisation of budding innovators in remote and other underserviced areas is a promising and significant shift. Combined with the campaign for broad-based social and grassroots innovation, under the banner of inclusive innovation, there is a real opportunity for taking the first steps to galvanising local systems of innovation.

From a systems and complexity perspective, the development of the NSI will take place in tandem with complementary initiatives at other levels of the economy. While the country is faced with major challenges at multiple levels of STI policy analysis, this cannot be used as a reason to put on the back burner the need for a more inclusive approach to innovation. The success of improved articulation between national STI policy and initiatives at provincial and local levels will require unprecedented levels of cooperation between the DSI and its national counterparts on one hand, and the vast sphere of provincial and local authorities on the other.

Furthermore, inclusive and grassroots innovation will be better served by concomitant developments in sector-based innovation systems as well as regional innovation systems. Individual innovators and SMMEs will benefit from being linked with local enterprises and other actors for technological learning and other economic benefits. A strategic clustering of economic actors in the different localities across the country, to facilitate knowledge transfer and technology spillovers, provide opportunities for interactive technological learning.

Ultimately, the inclusive growth and development of the South African economy will be driven by intersecting innovation networks at the level of the technology, sector, organisation, region or locality; with all ideally subsumed under an integrated and coherent NSI operating within a global system of innovation as depicted in the accompanying figure.

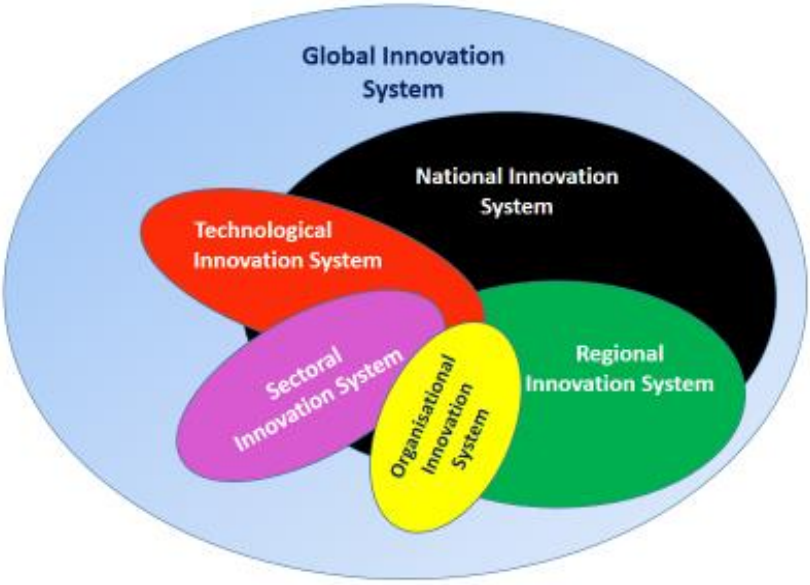

Figure 3.12: Different levels of systems of innovation
(adapted from Van Lancker et al.)[124]

3.3.4 NSI governance for improved coherence and coordination

All previous reviews of the NSI have found that there is little or no coordination of the system at national level and interdepartmentally. For this reason, there is a lack of coherence in the system. Opportunities for multisectoral cooperation are thus lost for lack of an overarching policy framework. There is also widespread duplication of effort and a concomitant sub-optimisation of resources. The NSI lacks a credible mechanism for bringing all the actors together in pursuit of system-wide goals and initiatives. Likewise, with few exceptions such as the innovative, ground-breaking and global scale SKA initiative, there is no integrated resource base for large-scale catalytic projects.

The STI-WP has developed a set of proposals to address this gap. These include the establishment of a standing STI Ministerial Structure, an annual STI Plenary to be convened by the State President and a strengthened NACI. The proposals concerning these structures are welcomed, and are discussed elsewhere in this report, alongside the Review Panel's own related proposals.

An aspect of NSI governance that warrants some analysis here is called the Strategic Management Model (SMM). In this respect, attention is also drawn to the recommendations made in the 2017 STIIL Review Report.

The SMM was proposed by the DST (at the time) as a mechanism for defining the roles and responsibilities of the respective government departments with regard to the management of public S&T institutions in particular, and the research enterprise in general. This model, first proposed in the 2002 National R&D Strategy, was designed to address an institutional milieu that was categorically characterised in that strategy as 'chaotic' and 'fragmented'[125]. The SMM was eventually approved by

[124] Van Lancker, J., et al., The Organizational Innovation System: A systemic framework for radical innovation at the organizational level. *Technovation* (2015), http://dx.doi.org/10.1016/j.technovation.2015.11.008i
[125] Government of the Republic of South Africa. 2002. *South Africa's National Research and Development Strategy*. Pretoria.

Cabinet in 2004. The roles and responsibilities for various scientific and technological activities (STAs) were delineated as in the corresponding table.

	Type 1	Type 2	Type 3
Type	Cross-cutting science and technology	Sector-specific science and technology	Critical technology services
Description	Long-term and cross-cutting RDI and HCD	RDI and tech transfer in relatively mature technology domains	Application of mature S&T in service deliver
Examples of STAs	Postgraduate research at universities	Research in science councils focused on the application of knowledge; targeted HCD	Police forensics, weather services, geological survey
Examples of implementing institutions	HSRC, CSIR	ARC, Mintek	South African Weather Service, National Health Laboratory Services
Responsible department	DST	Line departments	Line departments
Role of DST	Complete oversight	Support in case of market failures or serious technology gaps	None

Table 3.5: A synopsis of the 2004 Strategic Management Model (SMM) for STI

Ten actions were identified for implementation to give effect to the SMM, four of which were regrettably not implemented, being:

- the establishment of an institutional mechanism for the coordination of funding of tertiary education postgraduate research;
- creation of a research and technology transfer office within the DST to assist sector-specific departments;
- drafting a policy on governance standards for science and technology institutions; and
- drafting of coordinated legislation to operationalise the SMM.

According to the STIL Report, the SMM is the closest the NSI has ever come to providing an overarching policy and legislative framework for the governance of public research institutions. In fact, according to the STIL1 Report, had all the identified actions been implemented, "significant strategic alignment might have been achieved and greater clarity created about the distinction between Types 1 and 2 STA and their implication for the governance and oversight responsibilities of various government departments over PRIs."[126]

Much time has elapsed since the SMM was developed. The NSI has since grown and changed considerably. Nevertheless, those elements of the model that are still applicable should be implemented as part of an updated model, provided they are in sync with the new governance proposals outlined in the 2019 White Paper.

Such an updated model should provide more clarity on the distinction between Type 1 and Type 2 STAs, as well as Type 3 STAs. Newly established initiatives and their governance modalities, such as the 4IR and Operation Phakisa, should be factored into decision-making within a new model. And, the roles of other sector leaders, such as the private sector, civil society, provincial and local authorities, should also be accommodated.

[126] DST. 2017. *Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape*. Pretoria.

The opportunity provided by the integration of higher education and science and innovation within a single ministry should be used to develop a strategic management model that will clarify roles and strengthen coordination.

3.3.5 The diminished roles of the SOEs in the NSI

The state-owned enterprises (SOEs) are part of the inheritance from the apartheid system. The apartheid government had adopted an interventionist approach to the economy by establishing companies in certain significant industries to guarantee specific social, economic and political goals. Since 1994 new SOEs have been established, reflecting the importance attached by the democratic state to the SOEs in transforming the South African society to serve the interests of the new democratic order. Many of these SOEs operate as corporate organisations and are subject to the Companies Act. In some of the enterprises, government has full ownership, while varying levels of private equity is found in others.

Across all the dimensions of this analysis, the SOEs are implicated because of their singular important role in the country's economic landscape. Moreover, many of the SOEs operate in technology-intensive industries and therefore have or should have a significant footprint in the country's NSI. The NDP outlines the role of the SOEs as advancing the country's national objectives through providing economic and social infrastructure, through participating in economic growth and overcoming spatial inequalities[127]. In order to be able to play this role, the SOEs need to be well-governed, well-managed and operated efficiently and viably. However, in the instance of many SOEs, this has not been the case for many years.

As flagged in the foregoing discussion under 'Values', SOEs are dogged by a myriad of problems, many of which stem from corruption, maladministration, mismanagement and incompetence. For this reason, many of them are simply not in a position to contribute meaningfully to the objectives outlined in the NDP such as social and economic transformation in the country[128]. Some have been caught in the various contestations that are at play in the political economy, for example, by seeking to drive profits over development. However, the biggest drawback of many of the SOEs is their poor economic performance. For this reason, too many of them are perceived as taking away from rather than enhancing the living standards of the people of South African.

According to some estimates, the failing SOEs had a combined debt of close to R2 trillion in 2019; and subsequently the National Treasury has raised the country's gross debt estimate for the 2018/2019 fiscal year to 55% of GDP[129]. There is now a long history of rolling bailouts for many SOEs that have become a feature of the existence of these SOEs and a deep concern for the country's diminishing taxpayer base. Moreover, approved loan guarantees already amount to hundreds of billions of rands. This comes at a time when the economy is depressed and the country's tax base is diminishing, causing growing stress on annual national budgets. Supporting SOEs comes at the heavy cost of providing critical services to citizens such as social welfare for the economically distressed and basic infrastructure to the citizens. Yet the biggest cost of the SOEs to the country might be in the opportunities lost in correcting market failures, particularly in relation to technological development, which is so essential for redirecting the economy towards industrial development, employment creation, skills development and inclusive innovation.

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[127] RSA. 2012. *National Planning Commission: National Development Plan*. Pretoria: Government Printing Works.

[128] Thomas, A. 2012. Governance at South African state-owned enterprises: what do annual reports and the print media tell us?, *Social Responsibility Journal*, Vol. 8 Iss: 4 pp. 448 – 470.

[129] Gumede, W. 2019. *The Cost of Dysfunctional State Owned Enterprises*. Democracy Works Foundation, 22 February 2019. https://democracyworks.org.za/the-cost-of-dysfunctional-state-owned-enterprises/,

A study conducted by the HSRC found that there are serious bottlenecks in the R&D functioning of SOEs. These are brought about by a shortage of skilled technical workers who are critical for supporting R&D work; poor linkages of the SOEs with the global sources of knowledge; and, a negative impact on R&D budgets owing to improper procurement processes[130]. As the accompanying table shows, the contribution of the SOEs to R&D has never been spectacular, but has declined consistently between 2007/08 and 2016/17.

YEAR	NUMBER OF R&D PERFORMERS	R&D EXPENDITURE R'000	PROPORTION OF BERD %
2007/08	19	2 765 729	25.8
2008/09	21	3 438 543	27.9
2009/10	21	2 158 238	19.4
2010/11	19	1 685 520	16.8
2011/12	18	1 318 492	12.6
2012/13	19	1 512 021	14.3
2013/14	19	1 609 771	13.7
2014/15	19	2 019 919	15.2
2015/16	18	1 973 416	14.3
2016/17	16	2 621 883	17.7

Table 3.6: R&D expenditures of SOEs from 2007/02 to 2016/17[131]

The table shows the extent to which the SOEs as a collective have relinquished their critical and essential role in the NSI. Their participation in R&D has fallen in all key measures. The fall of the SOEs's share within the collapsing BERD to less than 18% demonstrates the diminishing role of this sector in the development of a knowledge economy. The success of the 2019 White Paper and the forthcoming Decadal Plan for STI is heavily dependent upon the revival of the SOEs within technology development and transfer. This is precisely because the footprint of the SOEs in the economy is a necessary asset for extending the participation and benefits of the marginalised actors in grassroots innovation.

There is an urgent need for the DSI, the Department of Public Enterprises and the relevant line departments to establish a joint strategy and action plan that outlines a roadmap that would revive the roles of the SOEs in R&D. This should outline goals and outcomes that are in line with the shared responsibility for promoting economic growth in the interest of job creation and reducing inequality. R&D should be incorporated in the comprehensive plans to rehabilitate and revive the SOEs to play their rightful role in the country's economy.

3.3.6 Leveraging systems and complexity for a coherent NSI

The foregoing analytical discussion of matters concerning systems which encompass the NSI and the various subsystems, is meant to contribute to redesigning strategic management and governance protocols that would result in a coherent, well-coordinated and inclusive system of innovation. As a conclusion to this section, it is worthwhile to recapitulate some aspects of this discussion.

As the post-Covid-19 world unfolds, South Africa is headed for an uncertain future that will certainly place added demands on the country's economy. As the efforts to rebuild the economy continues coupled with those to elevate the country's war against unemployment, poverty and inequality, much

[130] HSRC. 2018. The Future of State-owned Enterprises in South Africa: Why R&D matters. *HSRC Policy Brief*, March 2018. http://www.hsrc.ac.za/en/research-data/view/9205.
[131] [131] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.

is expected of our knowledge enterprise. The promise of a better life through investing in education and innovation will come under the spotlight. Soon, much higher returns will be demanded from the massive investments that have been made from the public purse in higher education and science and innovation. This is a credibility test that the HESTIIL cannot afford to fail.

The 2019 STI-WP promises to extend the benefits of STI to the marginalised groups through inclusive innovation. This is a colossal challenge as a multitude of demands are increasingly placed on a moribund economy. In the face of the unfolding future, South Africa cannot afford an NSI that is underperforming because of poor coordination and chronic incoherence. A whole new era must commence, and urgently so; one that takes on board past lessons. A reimagined and appropriately coordinated NSI offers opportunities for bringing into reality inclusive innovation that will contribute to addressing the most prominent challenges of this country.

In view of intense global competition, perpetuated by ICT-enhanced transnational capabilities of competitors, it is critical to accelerate, in the medium term, the transition of significant parts of the local economy to a knowledge-based one. The local productive systems need to be highly collaborative, multidisciplinary, multidirectional and inclusive. Applying systems and complexity thinking to the NSI is critical because of its intrinsic dynamic and evolutionary nature. The ideal NSI cannot be completely specified since its composition and operations are in a continuous state of flux. It is therefore important to avoid the pitfall of over-engineering the composition, operations and management of the NSI and thus fail to account for and leverage its autopoietic, self-adaptive and non-linear properties. The modalities of governance need to be agile to accommodate non-deterministic systems of production and high uncertainty in both the local and global markets.

The importance of a systems approach to innovation management is illustrated in the following case study of the **Pebble Bed Modular Reactor (PBMR)** project. When a project is driven solely from a technology push perspective, it may ignore other essential aspects as well as partners, resulting in a catastrophic failure.

Case study on the lack of a systems approach to innovation: PBMR

CASE STUDY 2: PEBBLE BED MODULAR REACTOR NUCLEAR POWER

In 1993, South Africa introduced the Pebble Bed Modular Reactor (PBMR) as a prospective 'Strategic National Demonstration Project' aimed at "exploratory evaluations to determine the feasibility of a small nuclear reactor used on this concept to satisfy the anticipated future growth of electricity demand."[17] Eskom had taken up a licence from Germany to produce a design that would generate electricity using gas turbines. In 1998, Eskom confirmed its intention to develop a 'demonstration plant' that would drive the commercialisation of the nuclear reactor technology both internationally and locally. In 1999, PBMR was established as a 'national strategic project'.

Strategic Intent and Technology Acquisition: The strategic objective of the PBMR was to provide South Africa with a viable and highly competitive option for coastal generation of electricity. Its aims were to "provide safe, clean, cost-competitive, versatile, adaptable and green energy"[18] and to ensure that South Africa "retained nuclear expertise…for developing a possible future nuclear power generation programme."[19]

Linkages, Research and Development: The Nuclear Energy Agency of the Organisation for Economic Cooperation and Development had "accepted…the inclusion of Pebble Bed Modular reactor coupled neutronics/thermal hydraulics…in its program."[20] The PBMR project developed partnerships with several international and local universities, science councils and institutions involved in nuclear research as part of its efforts to enhance R&D in nuclear sciences in South Africa. PBMR partnered with the Westinghouse-led consortium which had been awarded a contract by the United States Department of Energy "to consider the PBMR technology as a heat source for producing non-carbon-derived hydrogen." [21]

Absorptive Capacity: The PBMR technology was adaptable, cost effective and offered clean energy and passive safety features. These value offerings had the potential to make South Africa a competitive local and international power generator.

Foreign Direct Investment: The major financing for the PBMR came from the government of South Africa. The source of FDI was Westinghouse, which pledged a 15% share in PBMR (previously held by British Nuclear Fuels Limited – BNFL). In 1999, Eskom established PBMR (Pty) Ltd, taking up 100% ownership of the shares. The first phase of the project required a feasibility study to be funded by BNFL, Exelon, the Industrial Development Corporation (IDC), an economic empowerment entity and Eskom. A demonstration plant would be built and would earn each of the investors a stake in the successor company. However, this did not materialise.

Challenges: After the Department of Public Enterprises had transferred R6 billion to the PBMR company over the previous three years for "the funding of the operations and building of a demonstration power plant", [22] in February 2010, South Africa's Finance Minister announced that the government would stop funding the development of the demonstration power plant. In September 2010, the Minister of Public Enterprises announced the cancellation of the PBMR project to the National Assembly. It was formally stated that although the government had funded the PBMR, "no plant has been built and the PBMR board chairman … had declined to elaborate on how this money was [had been] spent"[23].

Reasons for the decision to close down PBMR were:

- Inability to secure an anchor customer or an anchor investor;
- Consistently missed deadlines;
- Construction of the demonstration plant had been delayed;
- No clients or investors had been secured. South Africa's only firm client, US power utility Exelon, pulled out in 2002; and, Eskom had not taken up the PBMR into its energy mix;
- The estimated investment required for commercialisation was R30 billion;
- Government had reprioritised its spending obligations following the 2008 global financial crisis;
- Westinghouse had withdrawn its plans to participate in the US nuclear plant programme;
- NECSA expressed the opinion that PBMR had focused solely on the technology without attending to the backlash of anti-nuclear sentiments;
- Nuclear generation is far more expensive than renewable energy;
- The PBMR's emphasis on the development of a project business plan as opposed to the building of the demonstration reactor plant;
- The design of the reactor had been modified at least five times;
- The direct-cycle electricity design was too restricted for potential investors and customers; and,
- The mismanagement of a significant investment by Eskom stands out as one of the factors for its closure.

Aftermath: Through the project the South African government retained, consolidated and expanded its nuclear skills and capabilities. Investments were made in developing a new generation of nuclear scientists and technicians. Ironically, the pebble-bed technology remained attractive and as a result, the United States and China took up the technology for further development. However, the opportunity for South Africa to establish a new nuclear energy industry had been lost. The PBMR became an example of why market adaptability is important for survival. In January 2020, Eskom expressed its decision to dispose of the PBMR.[24] Eskom's call for interest is for all or parts of the modular reactor project,[25] and as result the PBMR has gone on sale to commercialise the business, its intellectual property rights and assets.[26]

Lessons:

- Prior to South Africa's experience, the basic research associated with the PBMR had failed in Germany.
- There was no clear accountability and monitoring of the project plan and its outcomes.
- There was nominal investment from the private sector and the project had not been able to attract any venture capital.
- Eskom had set an "unrealistic schedule for a new technology in a country that had never developed and licenced a nuclear plant."[27]
- Although there were gains in the training of students and staff, no requisite knowledge base was developed on nuclear technology applications for electricity generation.
- There was no coherence nor coordination between the government departments involved; and,
- Despite energy being one of the most urgent developmental challenges for South Africa, only a few research councils and universities were involved.

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17 Ion, S et al. Pebble bed Modular Reactor—The First Generation IV Reactor to be Constructed. Nuclear Energy, 2004 no 43 1 February 55-62
18 PBMR http://www.pbmr.co.za
19 McKune, Craig 2010 Pebble Bed Modular Reactor Demonstration plant is Funded but not but not Constructed in South African Journal of Science 106(5-6), 2-4 in http:scholar.google. com
20 Reitsma, Frederic et al The OECD/NEA/NSC PBMR coupled Neutronics/Thermal Hydraulics Transient Benchmark: The PBMR—400 core design
21 PBMR http://www.pbmr. co.za
22 McKune, Craig 2010 Pebble Bed Modular Reactor Demonstration plant is funded but not but not constructed in South African Journal of Science 106 (5-6), 2-4 in http:scholar.google.com
23 McKune, Craig 2010 Pebble Bed Modular Reactor Demonstration plant is funded but not but not constructed in South African Journal of Science 106 (5-6), 2-4 in http:scholar.google.com
24 Pombo- Van Zyl, N 2020 Up For Sale: Eskom's Pebble Bed Modular Reactor in https.www.esi-africa.com
25 Ibid
26 Ibid
27 The National Energy Regulator of South Africa cited in Mckune, C. Pebble Bed Modular Reactor Demonstration Plant is Funded but not Constructed in South African Journal of Science 2010, 106 in http:www.sajs.co.za

3.4 People

"*Policy choices determine inequality outcomes*." (UNDP, 2019[132])

3.4.1 Background and orientation

The government has made significant investments in higher education and skills development programmes to address the low educational and skills levels and remediate an education and training system that was fragmented, dysfunctional and unequal[133]. The NDP regards education, and higher education in particular, as essential in maximising the capacity of people to fulfil their potential. Among other measures to address the country's research needs, the NDP calls for the universities to increase the number of PhDs graduating per year from the 1 420 achieved in 2010, to over 5 000 by 2030. To address the shortage of researchers at universities and other public research institutions, the government implemented various initiatives including the South Africa Research Chairs Initiative (SARChI), the DST-NRF Centres of Excellence, and various scholarship programmes.

A report by the Labour Market Intelligence Partnership (LMIP) indicates an upswing in the investments, enrolments and achievements in higher education, particularly in SET[134]. A host of other reports and measures suggest that the HESTIIL is responding to the various inducements to improve the country's high and very high skills base. Historic demographic disparities are being reversed as more women and black people are added to the country's researcher cohort. The improvement of the share of research publications by women, from 20% to 32% between 1998 and 2014, exemplifies this evolving transformation[135]. In this section we analyse the various trends within HESTIIL and the NSI from the 'People' perspective.

Among the four analytical dimensions that we selected for conducting this analysis of the country's HESTIIL, 'People' is located at the apex of the pyramid for a reason. The analysis of 'Values' – our shared conceptions of the desirable – established the ethical foundation for decision-making, in order to serve as a reference point for preferring and selecting certain options over others in the development of the HESTIIL. The 'Political Economy' analysis unfolded the realities of the socio-economic environment that we inhabit and seek to impact; it profiled the underlying forces that shape the operating landscape that the selected policies need to negotiate. The examination of 'Systems' took stock of the organising frameworks that are applicable to the South African innovation ecosystem, and the available levers for bringing about 'concertation' – the synergistic ordering of all actors, networks and institutions towards a coherent and inclusive innovation system. All these dimensions, and the efforts and resources invested in them, are designed to be of service to the 'People'. The following analysis of 'People' therefore, takes stock of the extent of human development in the country and people's capacity to contribute to, and benefit from, a well-functioning NSI.

In this dimension of the SWOT analysis we examine the human resources base of the system, taking into account the country's past performance, current efforts and future needs. Given the explicit goals of the apartheid system to stymie the development of blacks particularly in SET, human capacity development is one of the policy cornerstones of South Africa's democratic order. People

[132] UNDP. 2019. *Inequalities in Human Development in the 21st Century: Briefing note for countries on the 2019 Human Development Report – South Africa*.
[133] HSRC. 2018. *Skills Development Legislation as a Lever of Change to Reduce Poverty, Inequality and Unemployment*. HSRC: Pretoria.
[134] LMIP. 2016. *Skills Supply and Demand in South Africa*. HSRC: Pretoria.
[135] DSI. 2019. *White Paper on Science, Technology and Innovation*. Pretoria.

development and the maximisation of human potential are enshrined among the public administration values in the country's Constitution. On this basis, therefore, we invoke a critical perspective in the analysis to foreground empowerment and emancipation of the marginalised groups. The analysis will thus go further than the "headcount" or "FTE" or "units of output" analyses that confine people development to a utilitarian purpose. As a point of departure, we assert that STI and its economic impacts should serve the people and not the other way round.

We begin by adopting a broad framing perspective on human development before zooming into the specific details.

3.4.2 A broader look at human development

At first glance, South Africa's human development report makes for encouraging reading. Between 1990 and 2018, South Africa's Human Development Index (HDI) value increased from 0.625 to 0.705, an increase of 12.7%.

The HDI is a summary measure computed for measuring long-term progress in three basic dimensions of human development: a long and healthy life, access to knowledge and a decent standard of living. A long and healthy life is measured by life expectancy; knowledge level is measured by mean years of schooling among the adult population; access to learning and knowledge is measured by expected years of schooling for children of school-entry age; and, standard of living is measured by an adjusted Gross National Income (GNI) per capita.

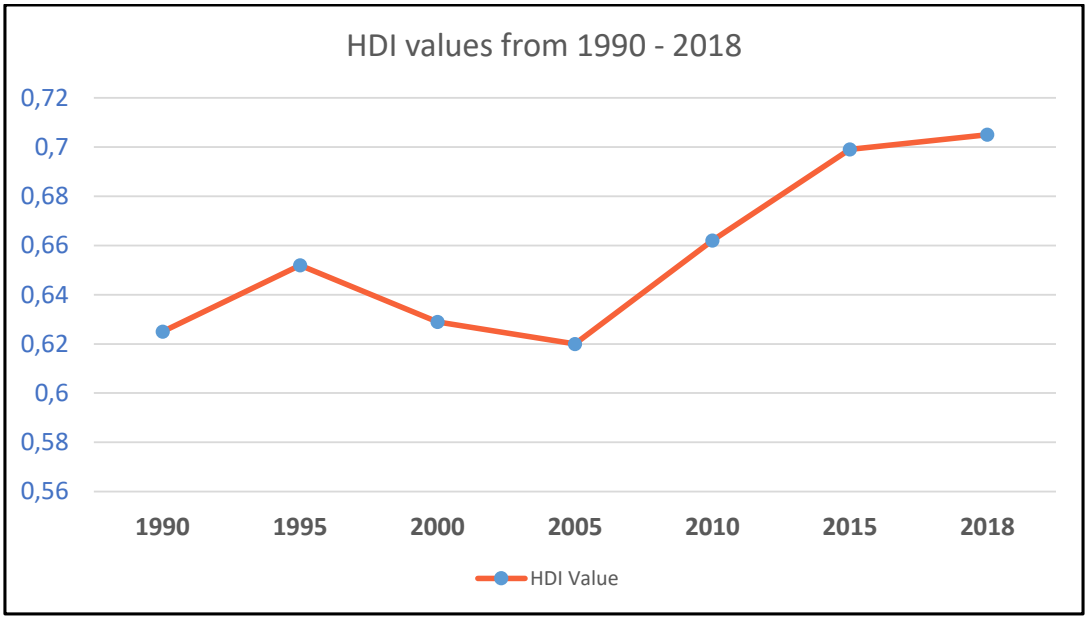

Figure 3.13: Time series trend in South Africa's HDI indices 1990–2018 (adapted from UNDP)

This significant improvement in the HDI is accounted for by increases across all three dimensions, with the stemming of HIV/AIDS-related deaths in the late 1990s and early 2000s (in which the supply of ARVs had a clear impact) and the resultant rebound of life expectancy. This can be seen in the accompanying table that depicts the breakdown of the components of the HDI. The data indicate that between 1990 and 2018, South Africa's life expectancy at birth increased by 0.5 years; mean years of schooling increased by 3.8 years; expected years of schooling increased by 2.3 years; and, GNI per capita at 2011 Purchasing Power Parity increased by about 22.6 percent.

Year	Life expectancy	Mean years of schooling	Expected years of schooling	GNI per capita (2011 PPP$)	HDI value
1990	63.3	6.5	11.4	9,588	0.625
1995	61.6	8.2	13.0	9,023	0.652
2000	56	8.8	13.0	9,498	0.629
2005	53.4	8.9	12.9	10,798	0.62
2010	57.7	10.2	12.8	11,723	0.662
2015	62.6	10.1	13.8	12	0.699
2018	63.9	10.2	13.7	11,756	0.705

Table 3.7: South Africa's HDI trends (adapted from UNDP)[136]

The expected years of schooling will likely show some improvement, should current trends continue. And, this should result in raised levels of education over time, as well as a stronger pool of candidates for tertiary education.

At face value, South Africa's HDI for 2018 (0.705) is pleasing as it places the country in the high human development category – albeit positioning it at 113 out of 189 countries and below the average of 0.750 for countries in the group. However, when the value is discounted for inequality, South Africa's HDI falls to 0.463, a loss of 34.4% due to inequality in the distribution of the HDI dimension indices.

Inequality is the most distinctive feature of South Africa's human development profile. Good aggregate indicators often conceal insidious stratification usually along the lines of race, gender, age, geographical location and other critical parameters. Inequality is the bane of South African society and calls for urgent policy attention and programmatic action. In addition to the current negative effects of inequality on society, it portends concerning socio-economic instability. The UNDP characterises the damaging effect of inequality as follows:

> *Inequalities in human development hurt societies and weaken social cohesion and people's trust in government, institutions and each other. They hurt economies, wastefully preventing people from reaching their full potential at work and in life. They make it harder for political decisions to reflect the aspirations of the whole society and to protect our planet, as the few pulling ahead flex their power to shape decisions primarily in their interests.*[137]

Inequality is not an accident but an outcome of 'policy choices'[138]. This is a sobering reminder about the stakes in this HESTIIL review and the important quest for a coherent, collaborative, inclusive and performing NSI.

3.4.3 Revealing inequalities in recent R&D statistics

In this section, we conduct a scan of the latest R&D statistics[139] to explore the nature and extent of inequality within South Africa's knowledge enterprise.

[136] UNDP. 2019. *Inequalities in Human Development in the 21st Century: Briefing note for countries on the 2019 Human Development Report – South Africa*.
[137] Ibid.
[138] Ibid.
[139] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.

The data on proportional R&D expenditure by provinces indicate the continuation of historical patterns of inequity to the detriment of the country's poorer communities. Over 80% of R&D expenditure is contributed by three provinces, i.e. Gauteng, Western Cape and KwaZulu-Natal. Based on the premise that R&D investment contributes to economic development, these patterns suggest that the odds are heavily stacked against provinces such as Limpopo, Mpumalanga, Northern Cape and Eastern Cape. The spatial distribution of future RDI initiatives across the country needs to redress this inequity and arrest any further distortion.

Concerted efforts to reduce gender disparity in R&D personnel appear to be bearing fruit. In 2017/18, of the 84 262 people working in R&D, 45% were women. The same proportion is maintained when researchers are isolated from that pool.

As illustrated in the accompanying figure, the racial profile of the researchers, excluding students, has improved over the past ten years. Nevertheless, whites continue to make up the largest proportion at 43.6%. This share increases to 47% when considering only the researchers that have a doctoral-level qualification.

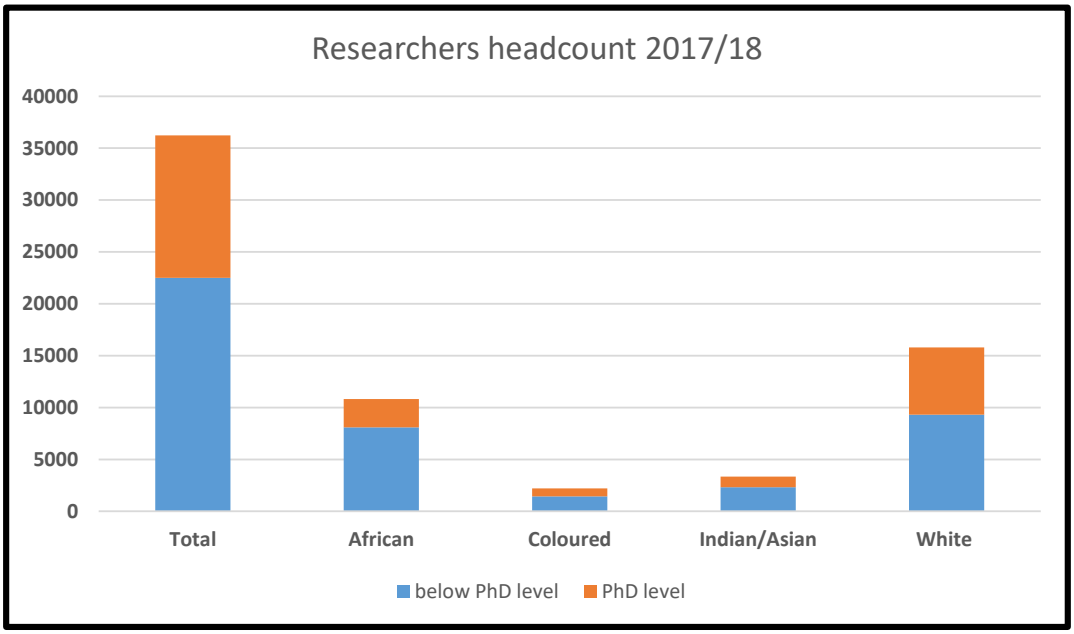

Figure 3.14: Researchers headcount 2017/18 (based on 2019 R&D survey results)[140]

Transformation in the business and industry sector is moving even slower. In 2017/18 only 27% of the 7 142 researchers employed in that sector were African, while whites accounted for over 56% of the total[141]. This breakdown should be seen against the fact that whites comprise less than 10% of the country's population.

On the positive side, overall expenditure has increased in medical and health R&D areas that disproportionately affect poor and marginalised groups. Expenditure in TB/HIV/AIDS and malaria-related R&D reached 11.9% of GERD in 2017/18 and environment-related R&D came to 7.3% of GERD.

[140] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.
[141] Ibid.

3.4.4 A historical survey of issues related to people in research

A historical survey of issues raised over the years, related to the participation of people in research, development and innovation, enables us to take stock of the improvements of the NSI in this regard.

The 2002 R&D Strategy highlighted an inadequate renewal of personnel, noting that the majority of scientific output at the time was from researchers aged above 50 years. The proportion of researchers per thousand of total workforce was below 1. The total contribution of women in scientific output amounted to 15%, while that of blacks remained in the single digits.

The 2007 OECD Review Report on South Africa emphasised the need to develop the STI human resources base, citing in particular the need to increase the completion rates for PhD degrees. In addition, the OECD encouraged the country to invest not only in R&D personnel but also in associated areas such as design, engineering and associated management areas. The OECD proposed the activation of opportunities in the private sector, finance investment bodies such as the Investment Development Corporation and foreign direct investment, as well as facilitating easier immigration of skilled people from abroad.

To address the human resources challenge, the 2012 Ministerial Review Panel called for a planned, concerted, well-resourced and sustained programme of action by all the relevant policymakers and performers. The panel described the problem as follows:

> *"…the present human capital development (HCD) system is locked into sets of inter-dependent 'pipeline jams', with piecemeal interventions having so far served only to make the system more refractory to positive change, in fact, the interventions have produced a peculiar and rather general resistance to the idea of any further policy change in a 'fatigued' system."*[142]

The panel recommended a range of interventions ranging from school level to tertiary education. Ireland was cited as a good international example to draw lessons from.

In their 2017 report, the STIL Panel proposed providing greater attention to the research component at master's level research to address issues of poor quality and throughput of postgraduate research production[143]. They further called for the expansion of the DST-NRF Centres of Excellence and the South African Research Chairs Initiative, citing positive results from investment in such initiatives abroad. The resourcing of universities was cited as an issue that needed attention as much was expected from underpaid and yet overworked academics.

From the above survey, it is evident that HESTIIL has come a long way. Many of the major challenges that were identified several years ago have since been addressed or great strides have been made in addressing them.

3.4.5 Some troubling NSI people management trends

This review draws attention to concerns and limitations regarding people management within the NSI. There are indications that while human competencies grow, appreciation of human endeavour is

[142] DST. 2012. *Department of Science and Technology Ministerial Review Committee on the Science, Technology and Innovation Landscape in South Africa*. Pretoria.
[143] DST. 2017. *Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape*. Pretoria.

diminishing. This is true also for Technology 100 companies, as shown in a survey conducted by the Da Vinci Institute for Technology Management.

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

Table 3.8: People management strategies by TT100 organisations (2018)[144]

The study revealed troubling trends in relation to people management practices in technology-based organisations in South Africa. In many of the organisations skilled staff are not provided the basic support normally associated with exemplary human management practices. In some cases, the deployment of people is not in sync with their competencies and there is a general lack of appreciation for specialised skills. Moreover, poor people management practices restrict individual growth and development.

Another prevalent attitude, found both in scholarly circles and in firms, has to do with a troubling regard for people simply as factors of production. This is illustrated by a concern often raised about graduates not fitting the requirements of industry. References to customising skills supply to meet demand should be tempered with a more nuanced philosophical framework of education and skills development that foregrounds self-actualisation rather than the utilitarian approach. In this way, education and skills development provide people a broader set of benefits than simply preparing them for employment.

The view that an increase in the supply of technical skills, in particular, is a ticket to economic growth and prosperity needs to be subjected to more rigorous analysis. The ever-growing spectre of unemployment in South Africa, as education levels increase, belies the core thesis of some of the human resources development policies. Far from blindly pursuing the seductive 'education for jobs' mantra, human resources development policies ought to invest in approaches that first and foremost promote human value and the more encompassing ideals of human dignity and self-actualisation.

3.5 Issues and findings

We summarise key issues and findings from the analysis, organised according to the analytical dimensions.

3.5.1 Values

- All HESTI policies reference social values directly and indirectly. This is a significant finding that resonates with the strong clarion call that came from the consultation with HESTIIL leaders - for a return to values. This lends credibility to the need for a values analysis of HESTIIL and the NSI.

[144] NACI. 2019. *South African Science, Technology and Innovation Indicators*. Pretoria.

- Although official documents are replete with references to values, they are eschewed in implementation and management practice. Performance plans, annual reports, human resource management protocols and STI project outlines give little to no attention to the country's value system at an operational level. This perhaps gives rise to the next finding.

- Various qualitative and quantitative measurements indicate that the country fares poorly in relation to proxies that estimate adherence to key values. In particular, ethics, accountability and efficiency are found to be ineffectively implemented.

- Social changes locally and internationally offer opportunities for a revival of values. These include the incorporation of values in the definition of environmental sustainability as well as inclusive innovation. Locally, there has been a strong rise in the levels of vigilance, debate and comment on the part of society, including in the voices of non-governmental organisations that insist on holding public officials and institutions accountable to the country's value system. This provides an enabling environment for fashioning a values-based HESTIIL.

- An analysis by the HESTIIL Review Panel identified the need to address some gaps in the country's value system. While South Africa champions values related to human dignity, equality, ethics and accountability, these do miss out on promoting aspects that support an entrepreneurial drive. This omission may be a function of the social, cultural and historical heritage of the majority of the country's people. Given the emphasis on innovation and entrepreneurship in STI policies, its definitive inclusion in the country's evolving value system is called for.

3.5.2 Political economy

- HESTIIL and the NSI are situated within and are inextricably linked with the country's political economy. On this basis, a political economy analysis should form a basis for higher education and STI policymaking and planning. Understanding the dynamics of the political economy, including a critical analysis of the power dynamics involved, will be essential for the reconfiguration of HESTIIL and the policies and plans thereof.

- Ongoing and vigilant political economy analysis is critical for a coherent and collaborative HESTIIL. The relevant government departments should regularly take stock of the dynamics in the political economy and respond accordingly, to ensure the integrity of the NSI as a coherent whole.

- The SWOT analysis reveals key forces that have direct implications for HESTIIL. These include tendencies and practices that are inimical to innovation and a people-centric policy regiment. Some of these tendencies are found in both the private and public sectors and can be invoked to explain some of the lost opportunities in technological innovation.

- Financial outflows, both legal and illicit, undermine the capacity of the economy to grow and the necessary private sector investment in R&D. Excessive financial outflows have also been proven to undermine industrialisation in the local economy.

- There are strong opportunities to design the future in a manner that will not only navigate but also leverage the defining influences within the country's political economy.

3.5.3 Systems

- The NSI conceptual framework has succeeded in organising policymaking and the monitoring and evaluation of knowledge-based activity in the country. Its conceptual evolution should specifically and comprehensively accommodate poor and marginalised sections of the population.

- The conceptualisation of inclusive innovation in the STI-WP should be expanded to include a rigorous analysis of the issues that motivate for inclusivity.

- The essential and critical role of SOEs as key actors within the NSI has diminished significantly. Their participation in R&D has fallen across all key measures which demonstrates the diminishing role of this sector in the development of a knowledge economy. The success of the 2019 White Paper and the forthcoming Decadal Plan for STI will rely heavily on a significant revival of the roles of the SOEs within the knowledge enterprise. The footprint of the SOEs in the economy is a necessary asset for extending the participation of and benefits for the marginalised actors in grassroots innovation.

- The NSI policy discourse has successively addressed the role of actors and networks, and this should be expanded to include intangible aspects that define the country's innovation context such as norms, values, power structures and the political economy.

- With regard to NSI governance for improving coherence and coordination, attention is also drawn to the recommendations made in the 2017 STIIL Report. An institutional model that will coordinate the RDI activities across all government departments is called for.

- The ideal NSI cannot be completely specified as its composition and operations are in a continuous state of flux. It is therefore important to avoid the pitfall of over-engineering the NSI and thus failing to account for and leverage its autopoietic and self-adaptive properties.

3.5.4 People

- South Africa has made great strides in human development, however the country's high level of inequality significantly limits the full realisation of the benefits of these great strides. While inequality already constitutes a colossal challenge for South African society, if unresolved, this harbours even bigger challenges for future social and economic cohesion and stability.

- The government has invested heavily in higher education and skills development programmes to address the low educational attainment and skills levels, and to redress an education and training system that was fragmented, dysfunctional and unequal. A report by the Labour Market Intelligence Partnership (LMIP) indicates an upswing in the investments, enrolments and achievements in higher education, particularly in SET.

- Various reports and measures suggest that the HESTIIL is responding to the various inducements put in place to improve the country's skills base, including improving gender and race disparities in participation and outputs.

- The results of an important survey suggest that in some leading technology organisations the level of talent management leaves a lot to be desired. Poor people management practices restrict individual growth and development while robbing organisations of the best from their people.

- The skills supply vs demand discourse should be tempered with a more nuanced philosophical framework of education and people development that foregrounds self-actualisation rather than the utilitarian approach.

The issues and findings listed above emanate from the Situational Analysis. Alongside those issues and findings that flow from other parts of this review, these are all considered in generating the final recommendations of this report.

3.6 Lessons from the COVID-19 response

The Review Panel is of the view that the analysis outlined above should form the basis of a new social compact for STI in the country. Relevant lessons should be taken from how various sectors came together to respond to the threat of the COVID-19 pandemic. The national response to the pandemic led by President Ramaphosa has received much praise for galvanising collective action that was anchored in shared values, was evidence-based, people-centred and inclusive, and leveraged the collective resources of the country's people. The country's response to the pandemic was largely informed by scientific advice. When, for example, the shortage of ventilators threatened to undermine the readiness of the country's health facilities to deal with the heightened demand, engineers within for example the Square Kilometre Array (SKA) and the CSIR, and universities found means to produce them, while some of the liquor distillers diverted their stocks of ethanol towards producing sanitisers.

These lessons in NSI collaboration can be found in the case study on South Africa's collective response to the COVID-19 pandemic reviewed below. Given the important role of STI in addressing poverty, unemployment and inequality, it could be argued that the challenges of the NSI are no less serious than the pandemic.

Case Study: COVID-19

South Africa's collective response to the pandemic

South Africa joined the world in the fight against the COVID-19 pandemic when Minister of Health Zweli Mkhize confirmed the virus to have spread into the country on 5 March 2020. Patient 0 was identified as a South African returning from Italy. Similarly, many confirmed cases that followed thereafter were of returning South Africans from various hotspots abroad.

On 15 March, President Cyril Ramaphosa declared a national state of disaster and announced immediate travel restrictions and the closure of schools from 18 March. Furthermore, on 23 March the President announced a national lockdown, starting on 26 March 2020. The National Command

Council on COVID-19 was established "to lead the nation's plan to contain the spread and mitigate the negative impact of the coronavirus". The Council comprised the country's foremost experts, including epidemiologists, clinicians and statisticians. This signalled that the government's response to the pandemic would be based on sound scientific advice. All these measures were instituted before the first fatality from the virus was confirmed on March 27.

On April 1, researchers from the NICD and the South African National Bioinformatics Institute at the University of Western Cape released the genetic sequence of the SARS-CoV-2 from a South African COVID-19 patient.

South Africa's bold and decisive response to the pandemic has been widely regarded as exemplary because:

- it was prompt and pre-emptive, placing the saving of human lives ahead of any other consideration;
- it was consultative, involving all sectors of society, including political opponents, civil society and the private sector;
- it was evidence-based, drawing on the advice of scientists and lived experiences abroad;
- although drawing advice from science, took into confidence the religious community, and thus managed to ensure compliance during periods of great religious significance for most of the population;
- it leveraged past experiences and capabilities used in the TB and HIV/AIDS campaigns, including promoting widespread testing;
- it made substantive efforts to address the economic impact of the lockdown on poor and economically vulnerable people;
- the President acted decisively in the face of the unknown and when some decisions were bound to attract criticism.

Government's response has not been without mistakes. There were some questionable decisions, such as the banning of private personal exercise and the public way in which disagreements within the Council played out. Some decisions appeared to lead to undesired consequences, for example, restrictions leading to large crowds or long queues which defeated the purposes of those restrictions. However, despite these, the President and his government are generally lauded for sparing South Africa the worst of impacts of the pandemic.

Chapter 4

Capacity analysis

4. Capacity analysis

4.1 Overview of HESTIIL capacity

4.1.1 Approach to the capacity analysis

The purpose of this section is to examine the institutional capacity of the HESTII landscape that is required to meet the needs of the South African people and economy for the benefit of society and the environment now and into the future.

The 2017 STIIL Review Report describes the evolution of the South African NSI and noted that "the new STI institutions established after 1994 are not primarily research performing and, while the NSI has developed, grown and diversified significantly, its institutional landscape has only changed marginally, with expansion largely taking place within existing institutions". The report further noted that there are numerous development imperatives that are inadequately supported by relevant public research institutions. Where there is some activity, this is suboptimal, and the relevant research initiatives were found to be too dispersed and thus subcritical.

The key challenge is to generate innovation activity in appropriate areas on a level that is sufficient to achieve a meaningful socio-economic impact for the country. Some of the problems identified in the NDP: Vision 2030 where STI can make a difference are a sluggish economy, a stagnating manufacturing base, severe socio-technical impediments to employment creation and service-delivery failures in the provision of basic services.

A distinct advantage of the existing HESTI institutional base is that, although small by developing country standards, it possesses pockets of world-class infrastructure and internationally recognised scientists, engineers and science practitioners. On this basis therefore there is a need to identify components that need to be grown to scale and where there are deficits in the HESTII landscape that require the establishment of new institutions or platforms. This calls for developing a shared understanding of the roles of the different components of the NSI; and, how these contribute to achieving the NDP Vision 2030, the policy imperatives of the 2019 White Paper, and the National Plan on Post-School Education and Training.

In this discussion, we present profiles of the different 'clusters' of organisations involved in a range of education, science, technology and innovation activities that are all geared towards achieving specific socio-economic advancements. It is important to note at the outset that these 'clusters' are fluid and not fixed and that the institutions involved often operate in more than one cluster. For example, the Agricultural Research Council (ARC) operates in the 'agriculture and food security' cluster while it also plays a role in the 'climate and earth sciences' area.

Accordingly, this review aims to elicit information that can be used in decision-making on the formation of new research institutions, the restructuring of some and perhaps even the closure of others. The analysis is based on the understanding that this review is not designed to provide a definitive blueprint to be followed as an instruction manual on redesigning institutions. Rather, it is intended to surface some pertinent considerations that should be addressed in the process of decision-making for the deepening and expansion of the HESTI institutional landscape.

This observation must be understood also in the context of the following requirement outlined in the Review ToR:

'The Review should be undertaken with the following prevailing assumptions:

(a) The existence of government mechanisms as envisaged in the STI-White Paper 2019, with reference to inclusive agenda setting and coordination across government being in place.

(b) The existence of an STI Agenda that is aligned to the National Development Plan (NDP) Vision 2030.

The HESTIIL Review ToR make it explicit that strategic choices have already been made and these are aligned with the national development objectives contained in the NDP Vision 2030. While there is no longer a need to test the alignment of the STI-WP with other government policies, there still remains the need to interrogate how the interventions envisaged by the STI-WP, the National Plan for PSET, the NDP, the National Industrial Policy Framework[145] and sectoral policies have been interpreted and translated into responses by the broader research community of South Africa. And, whether there are any institutional gaps remaining to effectively implement any of these policies.

The methodology used here involves a desktop review that draws upon assessments made within identified national priority areas of existing research capacity (i.e., researchers, research infrastructure and knowledge and technology outputs). As previously noted, the available literature across each of the priority areas differs considerably in nature (i.e., content), form (i.e., from scientometric studies to studies with a narrow focus on universities only or industry only participation), as well as in terms of methodology and purpose. This has made it impossible to use a standard approach for evaluating the performance of the NSI organisations across all the priority areas. For this reason, this discussion is set up to provide as much relevant information as possible on the NSI institutions active in each of the selected areas.

The review is therefore structured around the following issues:

(v) Socio-economic context, with line-of-sight on the NDP Vision 2030 and the STI-WP;
(vi) Investments in research and experimental development across the cluster;
(vii) The research base with a focus on researchers and research infrastructure; and
(viii) Direction-setting and governance.

The review is confined to a desk-top study based on available reports on government policy and strategy as provided by the DSI and as drawn from the websites of government departments, private companies, science councils, state-owned enterprises, civil society organisations and international organisations. With regards to research organisations, their Annual Reports and Shareholder Compacts can generally be relied upon as having been subjected to rigorous authorisation processes. Use is also made of review studies undertaken by official advisory bodies such as the National Advisory Council on Innovation (NACI). Amongst others, the National Survey on Research and Experimental Development conducted by the Centre for Science, Technology and Innovation Indicators (CeSTII) at the HSRC, assessments by the National Advisory Council on Innovation (NACI), review reports by the Academy of Sciences of South Africa (ASSAf), and the recently published scientometric study of the South African Research Enterprise by the National Research Foundation and CREST[146], all provide useful reference indicators and insights for this work.

[145] *National Industrial Policy Framework*, the dti.
[146] Ibid.

The findings of this analysis were tested on an ongoing basis throughout the HESTIIL Review process in multiple discussions with thought leaders in the fields of higher education, science, technology and innovation.

4.1.2 The current state of NSI organisations

4.1.2.1 Business sector

The National R&D Survey, in line with the Frascati Guideline, describes the business sector as comprising all industries and size classes of enterprises, including state-owned enterprises (SOEs). The Survey publishes aggregated findings across the business sector and only separates out the findings on state-owned enterprises. Given the time constraints for this study, the SOEs will be profiled separately and the high-level, aggregate statistics on the business sector will be used in this working paper. Where possible and depending on availability of information, reference is made to research activities/programmes and investments by specific private sector business entities.

Some key indicators of private sector R&D expenditure, excluding SOEs, sourced from the National R&D Survey 2017/18, were:

- Expenditure in R&D by the private sector was R 13.323 billion for 2017/18.
- The distribution across R&D types was 6.4% in basic sciences; 66.5% in applied sciences; and 27% in experimental sciences.
- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R 0.719 billion while current expenditure amounted to R 12.603 billion.
- Across fields of science, the highest area of investment for 2017/18 was the Natural Sciences and Engineering at 74.4%.
- The full-time equivalent researchers numbered 4 362 in 2016/17 which increased to 4 813 in 2017/18.

4.1.2.2 Government sector

The government sector includes national and provincial departments, municipalities, museums and public research institutions and laboratories but excludes the science councils. The largest expenditure here is in the research institutions, with the largest shares being across medical and health sciences (29%), agricultural sciences (22.5%) and social sciences (25.4%). There has been an increase in provincial investment in R&D, with Gauteng accounting for 41% and the Western Cape for 18.7%.

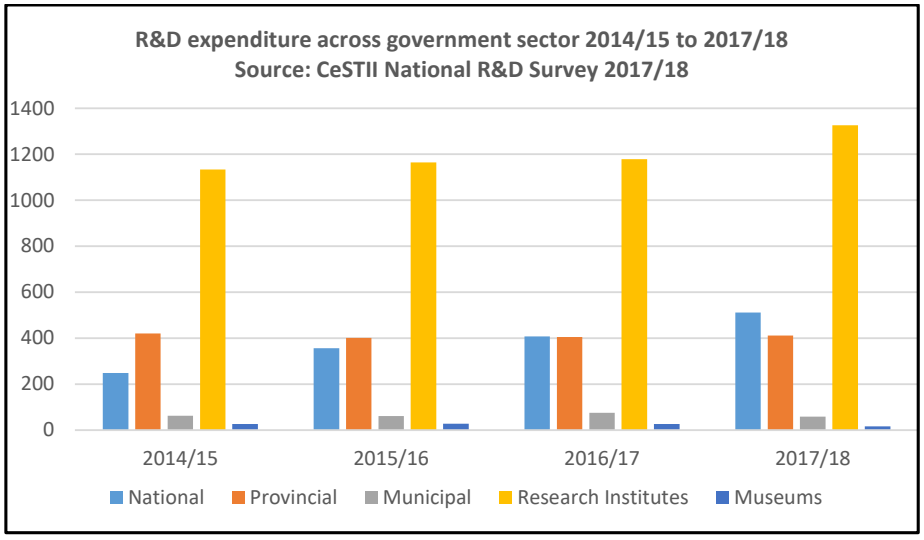

Figure 4.1: R&D expenditure in the government sector from 2014/15 to 2017/18

The government sector R&D investments according to the National R&D Survey 2017/18 were:

- The investment in R&D by the government sector has not seen real growth over the recent years, having grown from R1.893 billion in 2014/15 to R2.325 billion in 2017/18.
- The distribution across R&D types has been 14.2% in basic sciences; 72.5% in applied sciences; and 13.4% in experimental sciences.
- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R392 million while current expenditure amounted to R 1.93 billion.
- Across fields of science, the highest area for 2017/18 was in the Natural Sciences, Technology and Engineering at 74.1% of total spending. Included in this is the Medical and Health Sciences at 29%; Agriculture at 22.5%; and Biological Sciences at 9%. The Social sciences and Humanities came in at 25.9%.
- The number of full-time equivalent researchers is 899.

4.1.2.2 Science councils and other national facilities

Science councils and other national facilities are state-led organisations that hold a legislated mandate for conducting, primarily, directed research with the objective of targeted development within a specified economic or development sector. The arms-length positioning outside government departments is intended to afford the organisation a large degree of autonomy. This mandate then is expressed in terms of stewardship and accountability on targeted outputs and outcomes. The research agenda must always be aligned to the national development imperatives for the particular sector and, as a national scientific research body, must represent the authoritative face of the country on such matters to the outside world.

The 2017 STIL Review provided an extensive assessment of public-funded research institutions and recommended that, in the absence of an overarching policy or legislative framework setting out the generic functions of 'science councils', a reasonable starting point could be informed by the 'threefold

mandate for science councils'. This 'threefold mandate" was identified in a detailed HSRC study in 2016[147] in respect of the mandates of five such institutions. These are:

- The contribution to science and the body of knowledge;
- The contribution to technology, innovation and competitiveness for inclusive economic growth; and
- The contribution to innovation for government and communities in relation to the quality of life and for promoting social development.

The National R&D Survey includes the information that relates primarily to the Agricultural Research Council (ARC); the Council for Scientific and Industrial Research (CSIR); the Council for Geosciences (CGS); the Human Sciences Research Council (HSRC); the South African Medical Research Council (SAMRC); the Council for Minerals Technology (Mintek); and, the National Research Foundation (NRF). The investments by other publicly funded institutions are captured within the government sector.

The science council R&D fared as follows in the National R&D Survey 2017/18:

- The investments in R&D by the science councils over the period 2014/15–2017/18 increased marginally from R5 004 billion to R6 313 billion.
- The distribution across R&D types was 21.4% in basic sciences; 54.8% in applied sciences; and 23.8% in experimental sciences.
- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R823 million.
- Across the fields of science, the highest area of investment for 2017/18 was in the Natural Sciences and Engineering at 96.8% of total spending. Included in this is the Engineering Sciences at 18.6%; ICT at 17.8%; the Medical and Health Sciences at 16.2%; and the Agricultural Sciences at 15.7%.
- The full-time equivalent researchers numbered 1 792, which represents a drop of about 140 from the previous year.

4.1.2.3 State-owned enterprises

State-owned enterprises (SOEs) are public corporations owned by government that engage in market production and sale of the kind of goods and services often produced by private enterprises. As stated earlier, the statistics on SOEs are usually included in the business sector, however given the importance this is provided separately by the R&D Survey.

The same indicators used for the private sector are applied here for the SOEs, being:

- The number of SOEs with a significant level of R&D has dropped from **21** in 2009/10 to **16** in 2017/18 and, given the heavy toll that 'state capture' has taken on the SOEs in more recent years, it is likely that the number of R&D performers or investees has now dropped much further.
- The SOE investment represented about 17.7% of total business expenditure on R&D, however at one stage this was as high as 27%.
- The expenditure in R&D by the SOEs for 2017/18 was R 2 536 billion.
- The distribution across R&D types has been 5.6% in basic sciences; 74.4% in applied sciences; and 20.1% in experimental sciences.

[147] Glenda Kruss; et al. HSRC Press, 2016. *Balancing Multiple Mandates: The Changing Role of Science Councils in South Africa, 2016*. Available HSRC Press www.hsrcpress.ac.za

- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R702 million.
- Across the fields of science, the highest area for spending was the Natural Sciences, Technology and Engineering at 96.1% of total spending.
- The full-time equivalent researchers in 2017/18 numbered 668.6, which was up from 415.2 the previous year.

4.1.2.4 Higher education sector

The National Plan for Post-School Education and Training[148], described as a roadmap for post-school education and training, considers the consolidation of the post-school education and training sector comprising universities, technical colleges and community colleges as the start of a new journey. This sector seeks to generate the right sets of high to very high level skills for the country. The 2017/18 National R&D Survey shows that the higher education R&D expenditure amounted to R13 009 billion[149]. Universities play an important role in the generation of the human resources that underpin the country's economy as well as in conducting R&D.

Some of the R&D indicators for the higher education sector from the National R&D Survey 2017/18 are as follows:

- The investments in R&D by the university sector increased significantly from R8.377 billion to R13.009 billion.
- The distribution across R&D types was 55.7% in basic sciences; 32.8% in applied sciences; and 11% in experimental development.
- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R1.386 billion.
- Across the fields of science, the highest area of investment was in the Natural Sciences, Technology and Engineering at 61% and then the Social Sciences and Humanities at 39%. Included in the Natural Sciences, Technology and Engineering is Medical and Health Sciences comprising 19.6%, the Engineering Sciences at 7% and the Biological Sciences at 7%.
- The full-time equivalent researchers numbered 6 040, representing an increase of 942 from 2014/15.

4.1.2.5 Not-for-profit organisations

The National R&D Survey 2017/18 describes this sector as comprising non-governmental and other organisations formally registered as not-for-profit institutions.

The not-for-profit sector reported the following statistics in R&D according to the National R&D Survey 2017/18:

- The investments in R&D over the period 2014/15–2017/18 grew from R778 million to R1.216 billion.
- The distribution across R&D types comprised 23% in basic sciences; 54.4% in applied sciences; and 22.6% in experimental development.
- Of the total investment in R&D for 2017/18, the capital expenditure amounted to R75 million, while current expenditure amounted to R 1.140 million.
- Across fields of science, the highest area of investment for 2017/18 was in the Natural Sciences, Technology and Engineering at 90% of total spending. Included in this is the

[148] DHET 2019. National Plan for Post-School Education and Training (PSET), 2019.
[149] Ibid.

Medical and Health Sciences comprising 74.5% and the Agricultural Sciences at 5.2%. The Social Sciences and Humanities garnered 9.9%, which was dominated by the Social Sciences at 9%.

- The full-time equivalent researchers numbered 346 in 2017/18. This is about 50 fewer than the number of 396 in 2014/15 and gives credence to the concerns of local researchers that it is becoming increasingly difficult to source donor funds.

An important observation that can be drawn from the above is that the sector displaying the most significant growth in FTE researcher numbers for the period 2009/2010 to 2017/18 is the higher education sector. The accompanying figure shows that the private sector came close to the levels of the higher education sector in 2009/2010. However, by 2017/18 the higher education FTE researchers had almost doubled whilst that of the private sector had remained more or less static.

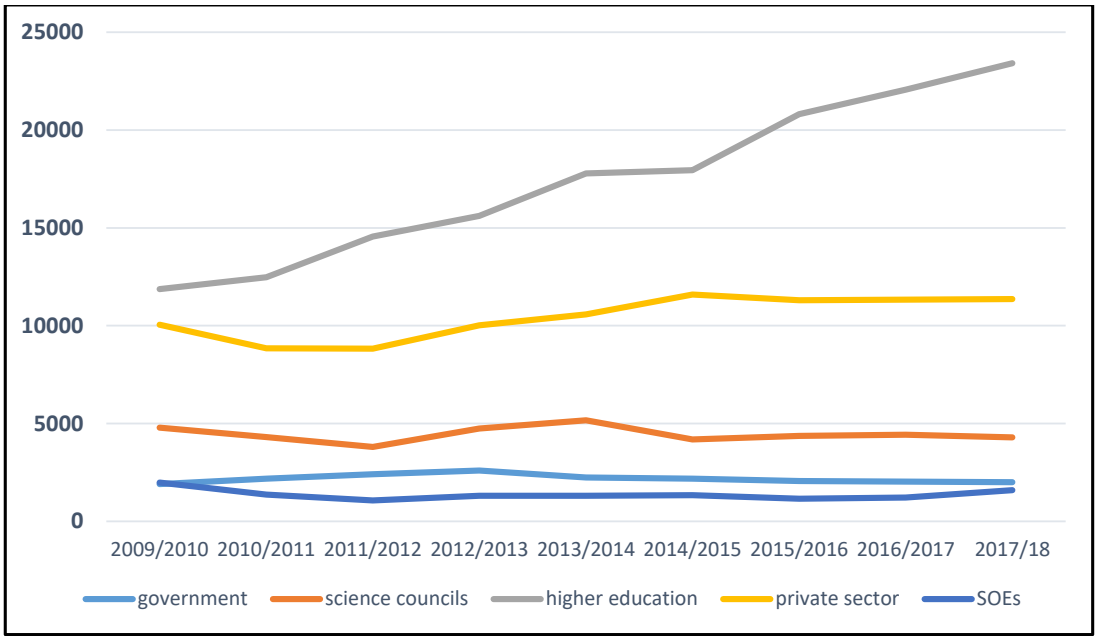

Figure 4.2: R&D personnel in full-time equivalents 2009/10 – 2017/18

A recent study cautions against reading too much in the apparent rise of university-based researchers[150]. This study suggests that closer inspection of the data shows that most of this increase is due to the growth in numbers of postgraduate students and postdoctoral researchers. The number of FTE researchers at universities declined from 5 098 in 2014/15 to 4 702 in 2015/16 – the first time this had happened in the last decade. Apart from constraining the growth of the country's research capacity, the poor levels of growth in FTE researchers for the universities can be attributed to the fact that university-based researchers are required to teach and supervise much larger numbers of students than 20 years ago.

While the above data conceal the reality facing the research base at higher education institutions, the lack of growth of FTE researchers in all the other sectors is self-evident. This means that, in general, most of the institutions and organisations within the NSI are not investing in the growth of R&D

[150] Mouton, J,. et al. 2019. *The State of the South African Research Enterprise*. DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy, CREST/SciSTIP. Published Stellenbosch University 2019.

capacity. Indeed, some appear to have been actively divesting since 2009. This trend is not consistent with the NDP goals.

4.1.3 RDI infrastructure

The 2013 South African Research Infrastructure Roadmap (SARIR)[151] report places research infrastructure at the centre of higher education, research and innovation. In understanding the ecosystem of large research facilities, an important observation in the SARIR report relates to the socio-economic value of research infrastructures from three complementary perspectives, viz.:

(i) The local benefits associated with the provision of technical/scientific activities and services linked to the site where the research infrastructure is located. This value is more clearly visible in single-sited research infrastructures or in nodes of a distributed research facility where users are located even if they access the facility remotely.

(ii) The added value for companies or research centres belonging to the research facility ecosystem, which provides components or specialised services for development and operation and which also generates a concentration of human resources. This intellectual innovation environment has an impact on the local schooling and culture, among other beneficial aspects.

(iii) The long-term induced value in the global innovation system which is related to the attractiveness for high-tech investments generated by the research facility operations and the positive side effects on other actors. From this perspective a wider range of socio-economic challenges are addressed.

The availability, quality and distribution of RDI infrastructure are all important considerations in the functioning of the NSI as a holistic and coherent unit. Cutting-edge infrastructure enables researchers and innovators to conduct quality work that can contribute meaningfully to the generation of knowledge and economic returns. Strategically located facilities can become strong attractors for partnerships and collaborations. World-class infrastructure provides opportunities for connecting local researchers and innovators to global counterparts, thus opening the country to possible technology transfer. In this respect, the following categories of infrastructure are all relevant and should be vigorously pursued:

- **Real single-sited global facilities,** such as the Square Kilometre Array (SKA) radio telescope that is currently under construction, are geographically localised unique facilities whose governance is fundamentally international in character.

- **Globally distributed research infrastructures** are research infrastructures formed by national or institutional nodes, which are part of a global network and whose governance is fundamentally international in character. The South African Earth Observation System (SAEOS) as part of the Global Earth Observation System of Systems (GEOSS) is one such example.

- **National facilities of global interest** are national facilities with unique capabilities that attract wide interest from researchers outside of the host nation. Antarctic or ocean-drilling facilities are typical examples. The MeerKAT has already demonstrated its potential in this respect by contributing to cutting-edge knowledge generation in astrophysics and cosmology.

[151] SARIR 2013.

It has not been possible in the context of this review to examine the role of infrastructure in the structure and performance of the HESTIIL. It is recommended that future studies of research infrastructure should examine their role in fostering global and continental collaboration and coherence as well as the extent to which they promote inclusive innovation.

4.1.4 Engineering capacity

One of the key findings of the 2017/18 R&D Survey is that most of the R&D conducted over the past ten years has been somewhat consistent in terms of levels of investment in the Social Sciences, Medical and Health Sciences, and the Engineering Sciences[152]. In the accompanying figure the report indicates that there has been a significant upward growth in the Social Sciences (from 10.7% to 23.7%), marginal upward growth in the Medical and Health Sciences (from 16.7% to 19.5%) and a significant decline in the Engineering Sciences (from 21.9% to 11.2%).

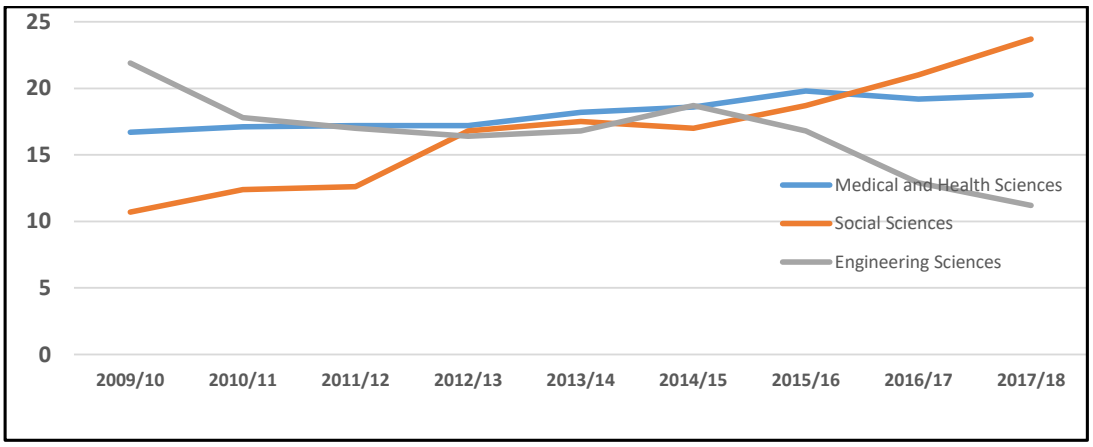

Figure 4.3: Proportion of R&D trends (%) vs GERD

The relative decline of the Engineering Sciences in R&D activities of the HESTIIL does not support the quest for a knowledge-based industrial development as articulated in the NDP. This is a worrying trend that we address in our recommendations.

4.2 The case for expanding the HESTI system

The Review Panel is ad idem with the finding of the 2017 STIIL Review that the country's STI system is underdeveloped. In order for this to remediated, the RDI base of the STI system has to be enlarged. Table 4.1 demonstrates that in terms of its number of full-time equivalent researchers, South Africa competes with India for bottom place, instead of with South Korea, Russia, Malaysia and China for the top spot. We argue that alongside capacity and excellence in science, engineering and technology is a precondition for any notion of social welfare. It is through these – capacity and excellence – that innovation becomes possible, and which in turn enables the achievement of the country's important societal equity and transformation goals. It is also through innovation that nature and its dynamics can be understood, so that in turn the resilience of ecosystems can be maintained, and that tools, raw materials, instruments and machines, spaces/places for work and creativity, and means of communication can enhance life. However, to make and track progress on these fronts we must

[152] Ibid.

distinguish between what these are and the human power and inventiveness that animate these. It is these capacities that are developed in the university system and which animate and are enhanced through the broader STI system. Development in both – universities and the broader STI system – has to be synergistic and transformative.

Country	Year for which data is available	Researchers/million inhabitants
South Korea	2017	7 597
Russia	2018	2 784
Malaysia	2016	2 396
China	2018	1 224
Brazil	2014	888
South Africa	2017	517
India	2018	216

Table 4.1: Researchers in full-time equivalents per million inhabitants. *Source: UNESCO.*

Increasing the country's RDI capacity is dependent upon increasing the availability of potential researchers from the post-school and the university system. In the latter case, it is about the quantitative production and the quality of master's and PhD graduates. To illustrate the gap in this output: when measured against the 2030 NDP output targets, in 2016 the university system achieved only 2.2% of PhD outputs as opposed 8.1%. On the positive side, master's and PhD enrolments have increased substantially since 2010. Master's enrolments have increased by 22% from 46 679 to 57 290, while PhD enrolments have almost doubled from 11 590 to 21 150.

Thus, the potential of populating the research base of the NSI system will be there if the total investment in RDI is increased from 1.0% of GDP to 2.0%. Such an effort and rise in expenditure could, over the next three years, see an increase of approximately 40 000 researchers, resulting in the country almost doubling its RDI researcher base. We have taken note that the Department of Higher Education and Training has an even more ambitious target: for 25% of students to graduate by 2030 with postgraduate qualifications.

Given the country's prevailing socio-economic challenges of high and enduring unemployment, widening inequality and worsening poverty, there is also enormous pressure for the post-school education and training system to respond far more effectively to current and future labour needs and appropriate areas of economic development. In this regard, implementation of the goals of the NDP requires the development of a projection of what the labour market would or should be (and not what the current one displays). It was the former Ambassador of China, Lin Songian, who pointed to South Africa's perennial flaw. He praised the country for finding very apt titles for its socio-economic development programmes: Reconstruction and Development Programme (RDP), Growth, Employment and Redistribution Programme (GEAR), Accelerated and Shared Growth Initiative (ASGISA), Radical Economic Transformation, New Economic Dawn, etc. Yet, in his view (which the Review Panel concurs with), each of these programmes reflected the inequalities and polarisations of the inherited system and failed to consistently achieve their aspirational titles.

Based on this analysis, South Africa could be confronted with a scenario of failure despite the best of intentions. The primary issue here, in our view, is not the employability or non-employability of research-savvy graduates, but the disappointing failure in absorbing their creativity within small, medium and micro enterprises, universities, research entities and SOEs. Both the RDP and GEAR envisioned, in opposing ideological ways, a full employment scenario with economic sectors that were globally competitive and with the accelerating numbers of small and medium enterprises mopping up the unemployment and informal sector maladies of the labour market. Instead, informal economic activity and high and enduring unemployment define much of our contemporary reality despite, on

CONTINUES ON PAGE 130 OF BOOK 2

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the face of it, ample interventions. Figures 4.4 and 4.5 demonstrate how the picture has remained unaltered since 2011 (Source: Small Business Initiative, SBI).

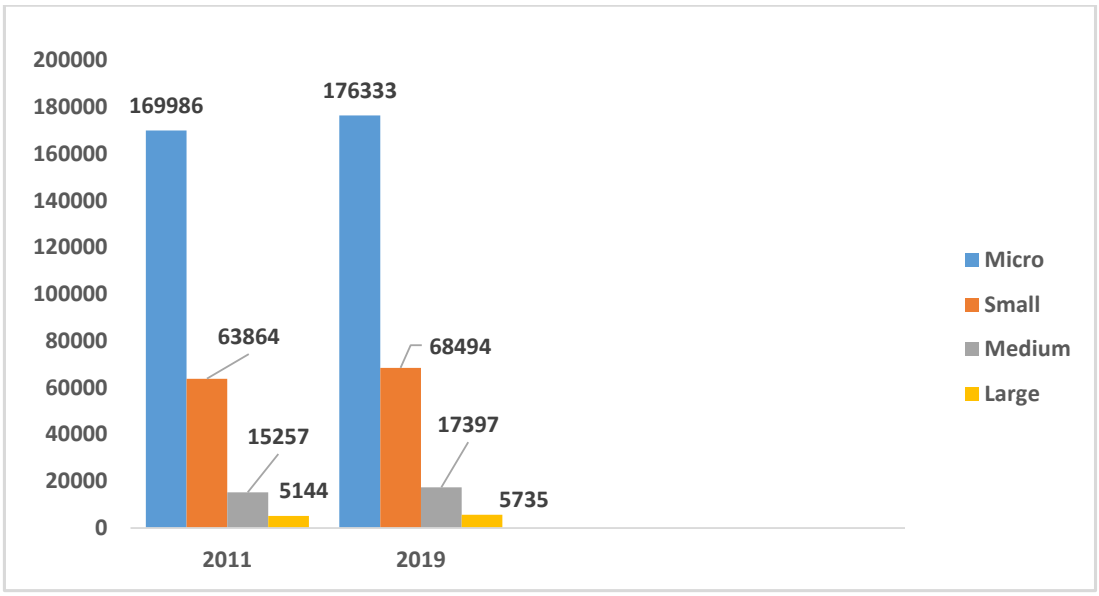


Figure 4.4: Number of firms in the SA economy 2011 – 2019

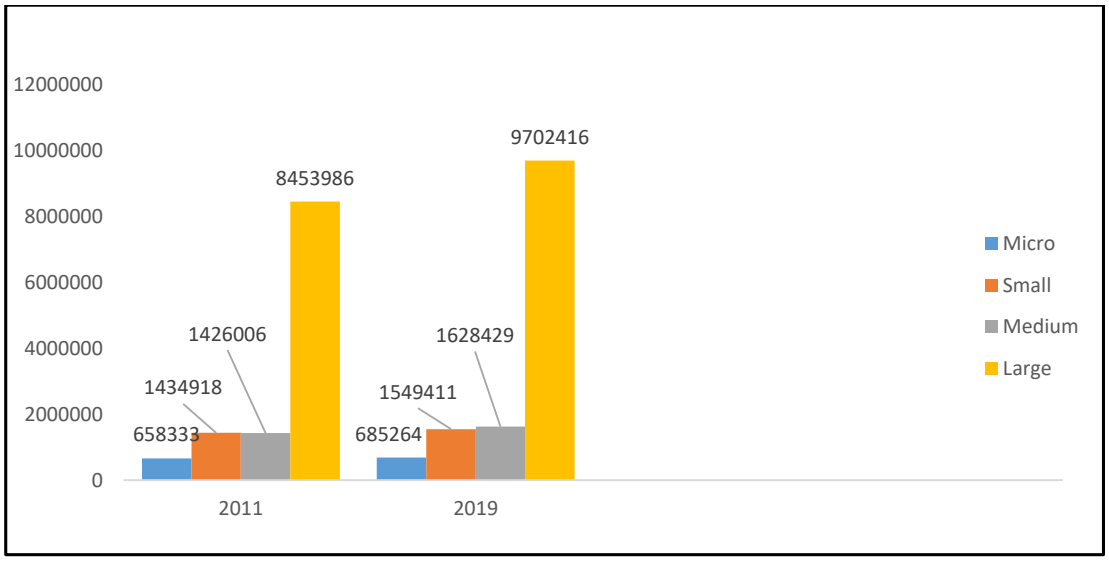
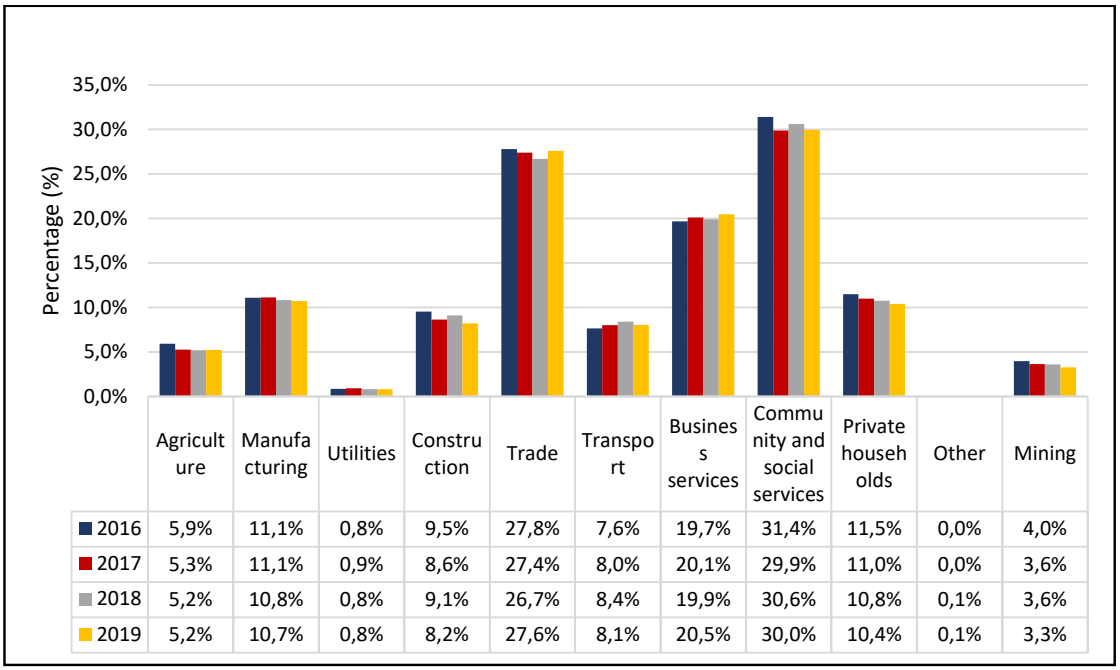


Figure 4.5: Employment in the SA economy 2011 – 2019

Figure 4.6 shows that the services and trade sectors employ the largest percentage of workers across the country's economic sectors. Over the period of this study, the greatest continuous job losses were recorded in four sectors: agriculture, manufacturing, construction and mining. Employment in construction continued its downward trend with the loss of 130 000 jobs, or 9% of its total workforce (REB, 2019). Manufacturing employment continued to decline, with 50 000 jobs lost in 2019. In contrast, the rest of the economy gained 510 000 jobs, almost entirely in business and community

services. Thus the rest of the economy created approximately half a million new employment opportunities in 2019 (REB, 2019).



	Agriculture	Manufacturing	Utilities	Construction	Trade	Transport	Business services	Community and social services	Private households	Other	Mining
2016	5,9%	11,1%	0,8%	9,5%	27,8%	7,6%	19,7%	31,4%	11,5%	0,0%	4,0%
2017	5,3%	11,1%	0,9%	8,6%	27,4%	8,0%	20,1%	29,9%	11,0%	0,0%	3,6%
2018	5,2%	10,8%	0,8%	9,1%	26,7%	8,4%	19,9%	30,6%	10,8%	0,1%	3,6%
2019	5,2%	10,7%	0,8%	8,2%	27,6%	8,1%	20,5%	30,0%	10,4%	0,1%	3,3%

Figure 4.6: Employment share in economic sectors (2016-2019) [153]

To simplify the contemporary picture of the employment pattern to advance our argument, the sectors could be organised into three as shown in Table 4.2. Note the further, albeit slight, shift from productive activity to the already dominant services sector.

Economic sector	2016 (% of employment)	2019 (% of employment)
Agriculture	5.91	5.25
Industry	25.39	23.05
Services	68.70	71.71

Table 4.2: Employment share per consolidated sector

Based upon this analysis, and in order to expand the RDI base so that we can elevate the NSI, two imperatives must be attended to. First, to produce knowledge-savvy senior graduates who can translate excellence in the applied fields into productive and creative outputs. And second, to provide research-savvy graduates who could form the RDI backbone to help usher in this expansion. Given that the new frontier of high-technology and Fourth Industrial Revolution competencies would be of paramount importance, a further imperative is to keep the strengths of the existing fields steady, but increase the research base in the fields of engineering and advanced digital technologies. For these ambitions to be realised, a concerted effort will be required from the Department of Higher Education and Training, through pivoting new resources and existing research output incentive schemes to

[153] Source: StatsSA (2019)

significantly increase the output of engineering graduates at master's and PhD levels, while keeping all the other fields of knowledge at their strength.

4.2.1 How has the higher education system responded to this national imperative?

The expenditure on post-school and higher education is shown in Table 4.3.

	2016/17 (R '000)	2017/18 (R '000)	2018/19 (R '000)
Public universities	23 838 867	36 213 172	38 646 641
TVET	7 354 648	7221 783	10 227 917
Community education and Training	2 182 259	2 285 105	2 231 154
Total for PSET	**37 375 775**	**45 720 060**	**51 105 532**
Skills Levy Fund disbursals (total)	**17 105 351**	**17 440 552**	**17 889 529**
SETAs	13 699 392	14 016 379	14 311 623
National Skills Fund	3 405 959	3 424 173	3 577 906

Table 4.3: PSET expenditure 2016/2017 – 2018/2019[154]

During the 2018/19 financial year, the total funding allocated to public PSET institutions was R51.1 billion. Public HEIs were allocated a larger portion of funding (R38.6 billion, or 75.6%), while TVETs and CETs were allocated R10.2 billion (20.0%) and R2.2 billion (4.4%) respectively. Funding of public PSET institutions has been increasing over the period under review (2016/17 to 2018/19), with funds allocated during this period increasing by R13.7 billion. The amount allocated to public PSET institutions in the 2018/19 financial year was R5.4 billion more than the amount allocated in the 2017/18 financial year. In 2018/2019, the largest increase was recorded for TVETs (R3.0 billion), followed by public HEIs (R2.4 billion), while funding for CET colleges declined in real terms (- R53 million). The largest amount of funding for public HEIs during the 2018/19 financial year was allocated to Unisa (R3.6 billion), followed by the University of Pretoria (R2.3 billion) and University of KwaZulu-Natal (R2.1 billion). Mangosuthu University and Sefako Makgatho Health Sciences University, both relatively new institutions with the lowest enrolments, were allocated the lowest amount, R360 million and R374 million respectively[155].

The total amount disbursed by the Skills Levy Fund has increased over the three-year period as reflected in Table 4.3. A larger proportion of the skills levy was paid out to SETAs (R14.3 billion), while the National Skills Fund (NSF) received R3.6 billion in 2018/2019. The NSF supported 297 projects with 59 051 beneficiaries in 2018/19. From the NSF 2018/2019 budget, R1.7 billion was allocated to student bursaries (46.2%), R830,1 million (23.2%) for rural development and R762.1 (21.3%) was disbursed to TVET colleges. National Student Financial Aid Scheme (NSFAS) funding allocations are shown in Table 4.4.

[154] Source: HEMIS database (2018). Figures are in real terms, deflated with CPI rebased to March 2019. Allocations above exclude NSFAS allocation*

[155] Because of substantial differences in fees, access to research funding and private donors, state funding does not reflect resourcing levels by institution (Makgetla, 2020)

	Public universities		TVET colleges		Total	
	No. of students	**Amount provided (' 000)**	**No. of students**	**Amount provided (' 000)**	**No. of students**	**Amount provided (' 000)**
2016/17	225 950 (50%)	11 571 350	225 557 (50%)	2 365 155	451 507	13 936 506
2017/18	260 002 (56.5%)	12 958 535	200 339 (43.5%)	2 153 751	460 341	15 112 286
2018/19	346 966 (51.9%)	18 803 806	239 797 (48,1%)	2 806 878	586 763	21 610 684

Table 4.4: NSFAS funding for public HEIs and TVET colleges (2016/2017 – 2018/2019)[156]

From 2018 to 2019, NSFAS funding for public HEIs and TVET colleges was allocated in the form of a bursary rather than a combination of a bursary and a loan. The largest share of the NSFAS funding allocated to public HEIs and TVET colleges in 2018/2019 was R21.6 billion, a 43,0% increase from 2017/2018, that was prompted by country-wide students protests for increased public funding to cap runaway fee increases and to increase participation of students from rural and urban poor and working class families. Public HEIs accounted for R18.8 billion and TVET colleges for R2.8 billion, indicating that universities received 87,0% of the fees proportion from NSFAS. As shown in Table 4.3, 59.1% of students in public HEIs were funded by NSFAS compared to 40.9% of students in TVET colleges.

According to the NSFAS Report (2018) and universities' annual reports, UJ (R1,6 billion awarded to 20 663 students[157]), UKZN (R1,6 billion awarded to 22 212 students[158]) and TUT received the highest NSFAS allocation, with Sol Plaatje University, University of Mpumalanga and Sefako Makgatho Health Sciences University receiving the lowest NSFAS allocations which were in line with their lower student enrolments.

Using the number of students funded against the disbursed amount per institution results in a per capita funding rate. This shows a range in university funding from a minimum of R13 605 to a maximum of R88 633, and an average per capita spend on students of R62 000. As stated in the NSFAS Report (2018), when the number of students funded at each institution is taken into account, Unisa (R 13 605) and VUT (R 44 095) are the institutions with the lowest NSFAS allocations per capita spend, while Rhodes (R88 633), the University of Pretoria (R83 932), Stellenbosch University (R82 636) and WITS (R81 688) have the highest NSFAS per capita spend[159], reflecting the higher fees asked by these four universities.

Table 6 shows that the highest proportion of students in public HEIs in 2018/19 were women (59,1%). There were 197 452 more female than male students in public HEIs in 2018/19 across all population groups. Enrolments in public HEIs were dominated by African students (both men and women) (75,6% or 820 619 students). White men and women account for the second highest enrolment rate (12,9%), followed by Coloured students (6,1%) and Indian/Asian students (4,4%). Table 4.5 shows student enrolment in public HEIs by race and gender.

[156] Source: HEMIS database (2018)
[157] UJ Annual Report 2018 https://www.uj.ac.za/about/registrar-portfolio/Documents/UJ-AnnualReport2018.pdf
[158] UKZN Annual Report 2018 https://www.ukzn.ac.za/wp-content/uploads/2019/12/Annual-Report-2018.pdf
[159] NSFAS Report http://nsfas.org.za/content/reports/researchreport_vital%20Statistics.pdf

There will always be tension between the policy priorities of government and research priorities within epistemic communities. Government policies evolve within a multi-lateral world system, inclusive of the G20, BRICS and the African Union, and within the country's own national long-term or short-term goals and plans. Epistemic communities also exist within world networks of knowledge production that are defined by disciplines, professional associations, and hierarchies of prestige and recognition. As knowledge continues to evolve as an economic driver, both poles of this tension are overlaid by corporate priorities and social pressures, which should be managed prudently so that opportunities for innovation are not foreclosed.

Race	Women	Men	Total
African	485 000 (44,7%)	336 000 (30,9%)	821 000
Coloured	42 000 (3.8%)	24 000 (2.2%)	66 000
Indian/Asian	29 000 (2.7%)	19 000 (1,8%)	48 000
White	80 000 (7.4%)	60 000 (5.5%)	140 000
No information	6 000 (0.5%)	5 000 (0.5%)	11 000
Total	642 000 (59,1%)	444 000 (40,9%)	1 086 000

Table 4.5: Number of students enrolled in public universities by race and gender (2018/2019)[160]

There is no doubt that the elements for the creation of an expanded research base are now in place. Most crucial for this Review is that the higher education system and in particular internal university choices and allocations have been moving in a direction that has served STEM disciplines (not necessarily engineering itself) well for some time as the distribution of students in public higher education between fields of study demonstrates in Figure 4.7.

Figure 4.7: % Distribution of students across higher education fields 2016

Even though, the shift and volume of effort have been remarkable, it is prudent to measure all this against the National Development Plan targets. This analysis is reflected in Table 4.6 below.

[160] Source: HEMIS database (2018). Figures rounded off to the nearest thousand.

NDP targets for Post-School Education and Training (PSET)

Heat map 'Trend Key' of progress on NDP targets for PSET

Progress but not enough to reach target	On track	Will not reach target at current rate of progress	No information available

Outcome	NDP 2030 targets for PSET	Baseline	Performance of PSET in 2018 and how this compares to NDP targets (current state)	Trend
Headcount and enrolment rates	Approximately three times as many students enter colleges each year compared to those entering universities.	892 936 students were enrolled in public HEIs in 2010, compared to 358 393 students entering colleges.	South Africa has seen a major expansion of student enrolment in both public HEIs and TVET colleges. 1 283 466 students were enrolled in universities in 2018 compared to the 977 256 students enrolled in colleges. In order to reach the NDP goals, university enrolment will have to expand to 1 620 000 while combined TVET and CET enrolment will have to expand to 2 250 000. Given fiscal constraints, reaching these targets will be particularly challenging.	
	Increase the participation rate at universities to at least 30 percent by 2030 so that enrolments increase to about 1.62 million from 950 000 in 2010.	950 000 enrolments in 2010.	1 283 466 students enrolled in higher education institutions in 2018. If growth continues at this rate, enrolments at universities should reach 2 million in 2030. Fiscal constraints are a major limiting factor.	
	Increase the number of master's and PhD students, including by supporting partnerships for research. By 2030, over 25 percent of university enrolments should be at postgraduate level. International exchange partnerships should be pursued and encouraged.		In 2018, there were 61 096 master's students and 23 650 PhD students enrolled in universities (7,8% of total enrolment in public HEIs). In 2018, 188 535 students were enrolled at postgraduate level in public HEIs (17,4%)[161]. According to DHET, if the share of postgraduate students enrolled in universities increases at the same pace in the remaining 13 years, between 2018 and 2030, the NDP target of enrolling over 25% students at postgraduate level will not be realised.	
	Expand the TVET and CET college system with a focus on improving quality. Better quality will build confidence in the college		977 256 students enrolled in colleges in 2018 (including CET, private colleges and TVETs). The college sector is on track to attracting more learners and is on track to accommodate 1.25 million learners by	

[161] Postgraduate students include all students in universities enrolled for Postgraduate, Below Master's Level, Master's and Doctoral Degrees.

	sector and attract more learners. The goal is to accommodate about 2 250 000 enrolments compared to the current 300 000.		2030, however the larger goal of a significantly larger combined college sector of 2 300 000 is at risk.	
Graduation rates	In 2030, South Africa will have over 10 million university graduates with a minimum of a bachelor's degree. This will be a 300% increase over a 30-year period (2001 – 2030).	South Africa had 2.6 million graduates in 2001.	From 2009 – 2018 (10-year period), South Africa has produced 807 150[162] graduates with a minimum of a bachelor's degree. Unfortunately, data for graduates pre-2009 is not available, however graduation rates were much lower pre-2009 compared to recent years.	
	There will be roughly 400 000 new university graduates each year.	In 2010, there were roughly 160 000 new graduates.	In 2018, there were 100 740 new university graduates from public HEIs; 123 696 when including private HEIs.	
	In 2001, South Africa had 2.6 million graduates (StatsSA) or one in every 17 people. In 2030 one in six people will be a university graduate. Many of the new graduates between now and 2030 must be in the critical skills categories, such as engineering, actuarial science, medicine, financial management and chartered accountancy.	South Africa had 1.1 million graduates in 2008 (StatsSA).	The total number of graduates in South Africa increased from 1.1 million in 2008 to 1.7 million in 2018[163] (StatsSA). That means 1 in every 34 people graduated in 2018. Similar to the previous years, the majority of graduates in 2018 were in Science, Engineering and Technology – 28.7% (65 211). Although there has been progress in graduate rates increasing, South Africa is highly unlikely to reach a target where 1 in 6 people will be a university graduate. The majority of new graduates are in STEM, however – on par with the NDP target.	
	Produce more than 100 doctoral graduates per million per year by 2030.	From 28 doctoral graduates per million in 2010.	The number of doctoral graduates per million in the population in 2018 was 58. This figure represents a 100% increase from that of 2010, when there were only 28 graduates. Total doctoral graduates in 2018 were 3 374 in both public and private HEIs. In order to achieve the NDP target of 100 doctoral graduates per million per annum by 2030, universities need to produce more than 5 000 graduates per annum. Impressive progress can be seen in the increase in the number of PhD graduates per million per year, but at the current	

[162] This figure includes graduates with a Bachelor degree from 2009–2018 for public and private HEIs (2018 only). In 2016 and 2017 figures for private HEI graduates, both Bachelor degrees and advanced diplomas are combined in a single figure.

[163] Not sure where the NDP got the 2.6 million figure from. StatsSA reference for 2018 figures: https://www.71point4.com/revisiting-graduate-unemployment/

			58 PhDs per million per year, it is unlikely that the NDP target will be achieved.	
Throughput rates	Increase the throughput rate for degree programmes to more than 75 percent. The number of graduates will increase from the combined total of 167 469 for private and public higher education institutions to 425 000 by 2030. As part of this target, the number of graduates in science, technology, engineering and mathematics should increase significantly.	From the combined total of 167 469 for public and private HEIs in 2012.	In 2018 the highest graduation rate was for postgraduates below master's level (46.8%) and the lowest for doctoral degrees (14.1%). The graduation rate for undergraduate degrees was 17.2%. The combined number of graduates from private and public HEIs in 2018 was 261 160. It is unlikely that throughput rate for degree programmes could reach more than 75%, especially because of high dropout rates after the first year of university owing to insufficient financial support and accommodation and transport being too expensive.	
	Produce 30 000 artisans per year by 2030.	From roughly 11 000 artisans in 2010.	South Africa is currently producing an average of 20 000 qualified artisans per year. The number needs to increase drastically in the next 10 years leading up to 2030 for the country to realise the NDP target.	
	Decrease the number of young people who are not employed or in education and training by 2030. There are currently about 3 million young people aged 18–24 who are not in employment, education or training.	In 2013, 3 million young people aged 18–24 were classified as NEET.	In 2018 there were 9.5 million young people aged 15–24 in South Africa. Of these, 34% (3.2 million) were neither working nor enrolled in any education institution such as a school, university or college. The number of young people nationally who are not in education, training or employment has remained remarkably consistent over the last decade. South Africa has made no progress towards this goal. If anything, according to 71point4 (2019), the number of NEETs has increased marginally. *Only 5% of children aged 15–17 is classified as NEET because the majority are attending school.	

Table 4.6: NDP targets for Post-School Education and Training (PSET)

Case study illustrating the effects of a discordant NSI: The Joule

One of the key requirements for growing the innovation system is the availability of funding. The uncertainty about funding sources proved fatal for the Joule.

CASE STUDY 4: THE UNREALISED DREAM OF SOUTH AFRICA'S JOULE

In 2005, the Industrial Development Cooperation (IDC), together with other government support, invested in the design and concept model of a six-seater, five-door passenger car named the Joule.[51]

Strategic intent: One of the strategic intentions of the development of the Joule car was to pioneer and advance an electric vehicle (EV) market and e-mobility industry in South Africa aimed at achieving "socio-economic benefits through local production of an element, or elements of the e-mobility chain".[52] Through the Innovation Fund and IDC, the government invested in an electric vehicle start-up business called Optimal Energy (established in 2005). This presented an opportunity for the country to become a key role player in an evolving global automotive industry through Optimal Energy's zero-emission environmentally friendly electric vehicle named Joule. Research and development on Joule was aligned to government priorities of job creation, technology innovation, economic potential and FDI, and above all, the 'justified risk' associated with environmental and climatic changes.

Institutional linkages and partnerships: Joule was developed as a prospective commercial success through manufacturing in South Africa.[53] There were important linkages in the sector that could result in a significant multiplier effect in associated industries (Deloitte 2012). Production support was made possible through the CSIR's Lithium Ion Battery Programme and the participation of local universities. Optimal Energy worked with the South African government, universities and international partners. It also worked with German and Spanish automotive engineering companies and employed the design expertise of renowned Jaguar designer Keith Helfet.[54]

Outputs, research and development: The R&D strategy focused on the following key aspects:

- Creating an enabling environment that "provides incentives for EV purchase, infrastructure investment and R&D;"[55]
- Pursuing and promoting the 'living-lab' approach to ensure the industry can adapt should the market change;
- Developing new EV designs;
- Incorporating the locally developed battery;
- Developing motor and software technologies; and,
- Establishing a new e-mobility industry.

Absorptive capacity: The local automotive industry's integration into the strategies of global companies has facilitated the development of South African designs and innovative products. These have also led to the upgrade of technological capabilities attained when the global systems are assembled. In addition, local firms "can enhance their local absorptive capacity by accessing a wide range of outside knowledge".[56]

Local and foreign direct investment: Although the Joule had received favourable reviews at the Genève and Paris motor shows, the Joule had not attracted any private funding for commercialisation and industrialisation. Instead, all investments came from government -

- The Innovation Fund and Department of Trade and Industry (the dti) financed the initial phase leading to the Joule's first prototype at a cost of R15 million.
- In 2007 the IDC purchased a stake in Optimal Energy and was keen to commence commercialisation activities.
- In 2008 the prototype was unveiled by the Minister of Science and Technology.
- In 2011, three roadworthy prototypes of Joule were tested on a budget lower than the models tested in the EU and US.[57]
- The Technology Innovation Agency (TIA) and IDC ultimately owned 80% of the project and at project closure, the associated IP.

Challenges: Although the Joule was well-received in European markets and global retail firms showed interest in sole distribution rights, later upscaling of the product proved to be a challenge due to lack of funding. Optimal Energy was unable to move towards the intended goal of producing a volume of 50 000 vehicles per year. Upscaling a complex product like Joule required an investment of R9,8-billion over a period of four years. A third of that funding was anticipated from government but did not materialise. The dti had expressed its commitment towards providing investment measures for the manufacture of the electric vehicle and components through the Industrial Policy Action Plan of 2010, but did not follow through on this commitment. In 2010 the Innovation Fund was incorporated into the newly established Technology Innovation Agency. This change in governance resulted in the premature demise of many Innovation Fund projects. Moreover, the IDC, which had funded Optimal Energy until 2011, made the decision to halt further investment.

The cash-strapped Optimal Energy closed its operation in June 2012. With four market-tested prototype vehicles, and a European market which had expressed interest in investing and taking up Joule, there were options that could have been explored to save Optimal Energy. However, government, as the main shareholder and IP holder through TIA and the IDC, did not prioritise exploring alternative strategies, leading to an immense innovation loss that could have contributed enormously to South Africa's re-industrialisation initiatives and a transformed socio-economic landscape.

Lessons:

- It is essential in the planning phases of large projects such as the Joule to consider the key criteria for the success of the commercialisation of innovation.
- Strategic government support and policy interventions have helped the South Korean automotive industry to claim at least nine percent of the global market by 2009. Such visionary market (and governance) leadership could have catapulted the Joule to taking up a large local and international market share.
- Funding hiatuses midway through the innovation cycle result in 'demonstration' products, processes, technologies and prototypes, but halt the commercialisation, industrialisation and globalisation potential of South Africa's industrial and knowledge economy.

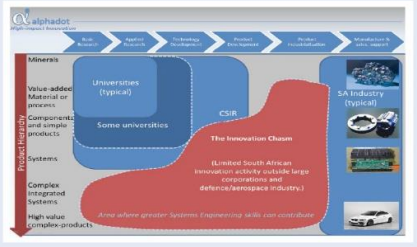


Figure: The Alphadot Innovation Matrix depicts the innovation chasm experienced by South Africa's NSI as a hindrance to local innovation reaching the industrialisation phase.

- The lack of funding and/or nominal funding provision for innovation coupled with the absence of alternative plans for funding by private and/or venture capital, adversely affects the commercialisation, industrialisation and globalisation processes and products.
- The Joule has highlighted the need not to focus efforts solely on technology; instead, in an industry that is characterised by great uncertainty, a diverse investment approach is essential.
- A great shortcoming within the policy and regulatory context is the lack of coordination and integration within and across departments.
- Given that transport energy demand "is expected to more than double by 2050 ... CO2 emissions will increase. EV or electronic mobility presents a potentially important option for reducing GHG emissions"[58] if the innovation, commercialisation and industrialisation chasm can be bridged.
- Despite growing investment by original equipment manufacturers in the industry due to South Africa's incentive programmes, not many have considered producing EVs in the country.

[51] Jennings 2011 cited in Dane Anthony, The Potential of Electric Vehicles to Contribute to South Africa's Green House Gas emissions targets and other developmental objectives
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The challenge facing us is without doubt a complicated one. However, in envisioning the future, one must always be aware of what has been achieved in the last two decades in the post-school and higher education system, such as:

- Global leadership in the applied arts and design, and deep research in decolonial archaeology, palaeontology, history and many forms of heritage;
- Strengthening of numeracy and actuarial experimentation;
- Finesse of the legal and ethical disciplines;
- Excellence in nutrition and dietetics;
- Expansion and deepening of indigenous botany and biodiversity;
- Processing of agrarian goods from fruit to plants into essential oils; and
- Expansion and deepening of digital humanities and science.

All these areas of progress should form the foundations upon which to bolster innovation in small and medium economic entities or in community-based non-profit and non-governmental organisations. Such excellence has to be nourished in both basic and applied research, although the golden mean between them is difficult to grasp: theoretical and particle physics and the international scholarship about them is as important as getting social systems to interact with renewable energy. Without the cognitive complexity of the one, our ability to apply will always be partial. This operates also at a trans-disciplinary level. For many years, the arcane and abstracted language philosophy practised by dons at Oxford and Cambridge seemed to be an exercise in obscurantism and elitism. But it was precisely its analytics that made possible the language of machines, of computers and now, of artificial intelligence.

The Humanities and Social Sciences appear strong in the system[164], but their 'success' was and is based on targeted interventions after the Charter of the Humanities (2011) and a concerted drive to define what is catalytic and what was a priority which was funded primarily out of the National Skills Fund. This was supported by generous Mellon Foundation funding[165] (which is unlikely to last much longer) and other international donor funds and partly through the NRF's Grand Challenge, some of its Flagship Projects and its South African Research Chairs initiative.

The challenge is to increase science and engineering capacities in the RDI system which will need three qualitative interventions:

- To increase the volume of master's and PhD enrolments and graduates in these fields;
- To link an incentive scheme towards work that creates new economic activities especially in manufacturing; and, finally
- To catalyse innovative small enterprises that advance value-added activities in the economy.

Prioritising knowledge-economy-linked research capacities is ostensibly precluded by our location in the world economy. Whereas production, circulation and exchange have moved east and south, knowledge, education and culture (more narrowly the knowledge economy) has remained west and north. Unless we get our admixture right we might lose out on both fronts. We are already swiftly losing our manufacturing base and our know-how capacity.

[164] Mouton, J,. et al. 2019. *The State of the South African Research Enterprise. DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy*, CREST/SciSTIP. Published Stellenbosch University 2019.
[S] See the *State of the Humanities and Social Sciences in South Africa Report* for AW Mellon drafted by Dr Ahmed Essop in 2015.

For the period under review (2008–19), unemployment increased across all racial groups. However, the incidence of unemployment was highest among Africans, with over 27%. Africans tend to be at a disadvantage in the labour market as indicated by the unemployment rates. Figure 4.9 shows that for example in 2019, the unemployment rate for Africans (32.3%) was more than 9 percentage points higher than for Coloureds (23.3 percent), 19.8 percentage points higher than for Asians/Indians and 25 percentage points higher than for Whites. Also for 2019, the unemployment rate for Coloureds was nearly ten percentage points higher than for Indians/Asians and 16 percentage points higher than for Whites.

With total unemployment in 2020 at close to 30%, and assuming that most of the unemployed were absorbed by small, medium and micro enterprises, that at present only employ 23.05% of the working population, then these enterprises will have to double in their capacity to absorb the unemployed labour. Now, given the requirements of very high-skilled roles precipitated by the Fourth Industrial Revolution coupled with the fact that the services and financial sectors are to be the first affected by this shift, it is now even more imperative to grow the RDI in a direction of new technology-savvy graduates across all the fields of knowledge.

While it may be difficult to determine exactly what work graduates do, we can identify the sectors in which they work and their main occupational terms according to Quarterly Labour Force Survey (QLFS) data. Figure 4.10 shows sectors in which young graduates (16–35 years old) with at least a bachelor's degree are employed. The private sector emerges as the leading employer by sector. In 2017, most graduates (67%) were employed within the private sector, while 26% of graduates were employed by the state and 2% employed by the NGO sector.

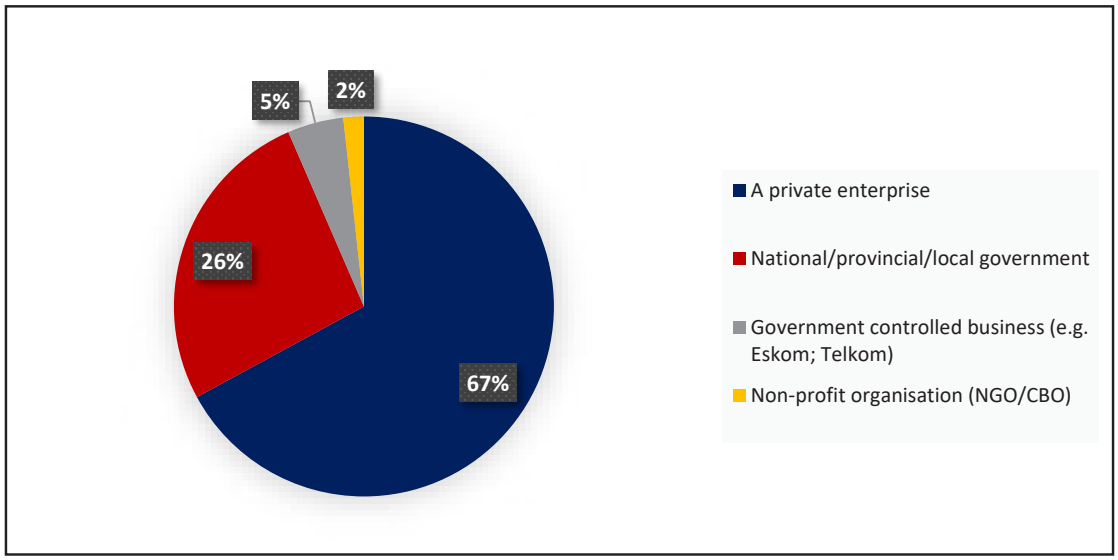


Figure 4.10: Graduate employment by sector (2017)[167]

Table 4.7 shows the top 15 main occupations of graduates – who hold at least a bachelor's degree and who are between 16 and 35 years old – for 2017. The results show that most graduates with at least a bachelor's degree worked in financial services (which include accountants, related accounting occupations and finance managers), accounting for 13.29% of graduate occupations. The results also show that 11.11% of graduates were employed as teaching professionals in primary, secondary and teaching associate jobs. The legal profession accounted for 3.39% of graduates. Business professions

[167] Source: LMD 2017 data (StatsSA).

made up of consultants, personnel and career professionals accounted for 5.09% of graduate occupations.

Main occupation	No.	%
Accountants and related accounting occupations, accounting	33 364	6,70%
Finance and administration managers/department managers	32 790	6,59%
Other office clerks and clerks not elsewhere classified	29 291	5,88%
Primary education teaching professionals	27 394	5,50%
Advocates, attorneys and related occupations, lawyers/attorney	16 886	3,39%
Business professionals not elsewhere classified, consultants	15 821	3,18%
Secondary education teaching professionals	14 383	2,89%
Medical practitioners, physicians, medical specialists	13 013	2,61%
Computer systems designers and analysts	11 505	2,31%
Directors and chief executives	12 927	2,60%
Teaching associate professionals not elsewhere classified	13 531	2,72%
Technikon, teacher training, technical and other colleges	9 021	1,81%
Mechanical engineers	10 021	2,01%
Personnel and careers professionals, consultants: management	9 518	1,91%
Computer programmers	7 438	1,49%

Table 4.7: Graduates (16–35 years old) by main occupation (holding at least a bachelor's degree) for 2017[168]

Unemployment among graduates with a Bachelor's degree was 10.8%; those with a bachelor's degree and post-graduate diploma was 7.8%; those with an Honours degree was 8.1%; and those with Master's or PhD degree was 2.1%.

What is obvious from available reports on flows of remittances for consulting is that most research-savvy graduates of the existing system are absorbed in knowledge and consultancy work outside of the R&D system. Contemporary trends in corporate life and government departments show that these rely heavily on focused and solution-driven research that is undertaken by an enormous array of consultants/knowledge workers. Most university graduates and post-graduates work in this sector. Corporates in South Africa spend R 70 billion per annum on such work in a sector that employs close to 60 000 people.[169] Disconcertingly, there is a disproportion between global and transnational expert firms and local firms in terms of the shares in this lucrative field, with the majority of researchers in either of these being South African graduates. Furthermore, national and provincial government departments have spent approximately R 30 billion and municipalities R 3,4 billion on such research work. Even in these instances, the global firms are earning a majority share of this. This expenditure is ten times the expenditure of the DSI's budget and more than the DHET spends as productivity rewards for the university system. There are, furthermore, a range of NGOs, non-profit and faith-based entities that conduct research for other NGOs, CBOs, social movements, trade unions, social partners and welfare associations. Crucial to note here is the declining consultancy/knowledge work budgets of SOEs that could be playing a leading role in helping to enlarge the research and development base in the country.

[168] Source: LMD data 2017 (StatsSA).

[169] Mc Gregor's *Who Owns Whom* provides sectoral reports on South Africa's economic landscape; the latest account of this sector is from 2019. It is titled *Management Consultants and Business Advising Services, Including Knowledge Management*, 26 April. For a quick look at figures see also Consulting. Coza. 20th Nov 2017.

4.3 Analysis of RDI programme clusters

The 2017 STIIL Review[170] opined that '*the establishment of national research institutes in key strategic priority areas will greatly enable the research and innovation system to perform at a level capable of enhancing South Africa's position as a leader among its peers'*. This can be achieved, among other things, by expanding the research base to ensure adequate capability to meet government policy objectives. The establishment of new institutions must factor in what the existing role-players are mandated to do and where the gaps lie in terms of national policy imperatives.

The process of identifying gaps in existing programmes is complex, as South African research institutions have proven agile in adjusting programmes to accommodate changing articulations of development problems. Recent reviews suggest that the economy will benefit from highly focused or mission-intensive institutions, rather than from sub-critical disbursements spread out across many institutions. Consolidation and better coordination are some of the critical success factors in invigorating the NSI.

The profiling of this 'capacity' for research, technology development and innovation finds expression in a range of assessment methodologies and scientometric instruments found in the source documents used for this study, and ranges from survey reports covering investment expenditure in R&D profiled in terms of capital and operational costs; human capital in terms of headcounts and full-time equivalent numbers of researchers, technicians and support staff; production outputs in terms of university graduates, publications and patents; as well as royalty income from licensing technologies and other knowledge holdings.

There are a few lessons to be drawn from previous cycles of priority setting in the science system, chief amongst which is to focus on a few that offer significant impacts on the socio-economic development objectives. The focus areas listed below attempt to address this with an articulation of the clusters in a way that can accommodate existing critical science, technology and innovation along with the forward-looking priorities that are drawn from government's development agenda and the highly consultative NACI process that culminated in the published report on the NACI Foresight Exercise in 2019.

Based on the above, this section examines the institutional capacity of the NSI in the context of specific socio-economic priority areas as opposed to the narrower set of missions. The analysis develops a perspective on the socio-economic backdrop attendant to each area. It explores the evidence of R&D investments (in research activity and human capital) and the performance profile of the performers (business, universities, science councils, civil society and SOEs). Finally, it provides some information on the coordination responsibilities and how effectively they are executed.

4.3.1 Health and well-being

4.3.1.1 Socio-economic context

The COVID-19 global pandemic that is wreaking havoc in families, communities, nations, continents and on the planet is testing the capacity of nations on a number of fronts. In particular, it has challenged in fundamental ways health systems globally, and it has exposed fault lines within the health systems of even the well-resourced nations of the world. Prior to the arrival of this global

[170] Mouton, J,. et al. 2019. *The State of the South African Research Enterprise. DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy*, CREST/SciSTIP. Published Stellenbosch University 2019.

pandemic, South Africa's economy and health system had already been under immense strain. When the President of the Republic declared COVID-19 a 'National Disaster' and imposed social and economic restrictions, the country's prevailing social and economic crises deteriorated much further.

This section focuses broadly on the research enterprise and healthcare issues of South Africa, assuming that the challenges of COVID-19 will eventually pass. The question that needs to be addressed is, to what extent is the country's current education, research, development and innovation capacity and infrastructure ready to meet the widening challenges of the nation's health and well-being? Is the health system adequately positioned to respond to the growing threat of both communicable and non-communicable diseases, whilst maintaining a state of readiness to scale up and rapidly and effectively respond to future pandemics such as COVID-19? In this regard, it is crucial to maintain line-of-sight from the underpinning education system and research enterprise through to the health sector and business sectors. The research enterprise encompasses the entire spectrum of sciences – medical and health sciences, human and social, and engineering (inclusive of the field of ICT and advanced digital technologies).

It is these questions of capacity and capability that have provoked the best minds across the world to find definitive benchmarks and modelling to guide planning, decision-making and effective implementation of responses. In the medical and health sciences fields, this includes having adequate numbers of medical and health professionals; facilities that are certified compliant for the production of vaccines; supportive drug-development laboratories; specimen testing; health accommodation facilities for quarantine; intensive care equipment; and other material resources. In South Africa and in many other countries, there is recognition that capacity is a serious problem. And, that the courageous fight by the medical and health fraternity is geared primarily towards 'coping' as best as possible with a system that could be overwhelmed every time before the COVID-19 global pandemic reaches its next peak.

With the spotlight intensely focused across the health system, it has heightened awareness of the formidable array of policies, strategies, institutions and regulations that have been established over the past twenty to thirty years in South Africa's fight against disease – infectious (communicable) and non-communicable. The country also carries on its shoulders the regrettable burden of many lives lost to the HIV/AIDS pandemic when reputable science was ignored. The journey since the advent of democracy has not been an easy in other respects also. It has been mired in conflict-ridden contestations, particularly so given that the country's highly developed private healthcare sector and pharmaceutical industry do not accommodate the healthcare needs of the majority of the population.

It is in describing the South African experience, both the journey over the past twenty-five years and the current fight against COVID-19, that an appreciation is developed that a more holistic view of 'health' is imperative. It is about the knowledge base (science), government and the people, broader industry and the performance and relationships across these that defines the capacity of the healthcare system. Attention to the broader industry is important in this discussion because, as the COVID-19 pandemic has acutely taught us, the healthcare professionals need manufacturers to supply equipment and protective gear; the food and pharmaceutical sectors to produce vaccines and drugs; and to ensure that people do not starve during confinement periods.

4.3.1.2 Research and experimental development and investment

The National R&D Survey 2017/18 statistics provide the following perspective of research activity with respect to investments in the fields of medical and health sciences across sectors, inclusive of the private sector. Figure 4.11 below shows that for 2017/18 there is a healthy distribution of research activity across business (private sector) and the higher education sector. The level of government

investment, which covers many of the key public laboratory and vaccine development facilities, is however quite disappointing. What is significant is the proportion of non-profit organisations' investments in this area, and that this is more than that of government and close to the level of spend of science councils. In the time of global economic crisis associated with COVID-19, and which is being projected as being as severe if not worse than the 1929 Great Depression, this vital support by the non-profit sector may drop dramatically, and many critical research programmes may be terminated.

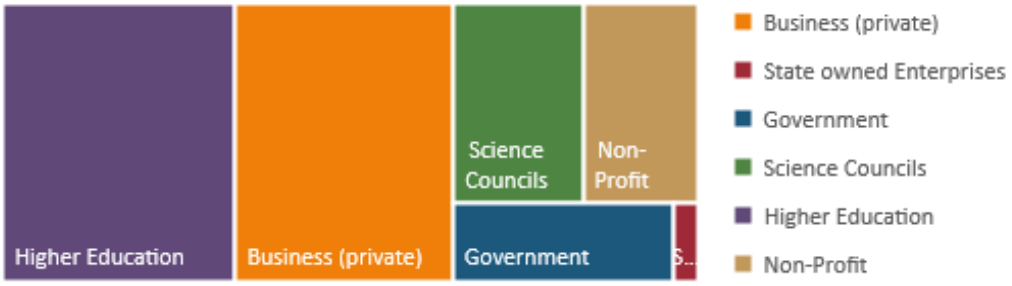


Figure 4.11: R&D expenditure by sector on Health and Medical Sciences, 2017/18

4.3.1.3 The research base

This analysis benefits from the considerable number of studies of health research in South Africa undertaken over the past ten years or so. Considerable focus is therefore on these studies, findings and/or research strategies which include the 2018 work of the National Health Research Committee, the 2019 CREST study on the State of the South African Research Enterprise, the 2009 ASSAf study on revitalising clinical research and related training in South Africa[171] and the Health Systems Trust: South African Health Review[172].

Researchers

The research development and innovation enterprise is thriving despite the neglect and poor performance of the health services sector in terms of the national goal of achieving a high degree of universal healthcare coverage. The CREST State of the South African Research Enterprise examines the research capacity of the sector and provides considerable insights into the health sciences research performance across universities and research institutions[173]. What is quite valuable is that the study looks at the capacity of the system to supervise the next generation of academic and knowledge workers. Some of the key observations include:

i. Health Sciences research grant holders increased substantially from **89** in 2002 to **681** in 2015;
ii. The substantial growth in total grant funding from R24.8 million in 2002 and R214.2 million in 2015 accounts for this increase in researcher numbers;
iii. Of particular note is the observation that the age profile of health researchers shows an increase in the number of researchers under the age of forty and a small number over the age of sixty;
iv. Permanent staff in the Health Sciences increased from 1 571 in 2002 to 2 223 in 2015;

[171] Academy of Science of South Africa. (2009). *Consensus Report. Revitalising Clinical Research in South Africa. A Study on Clinical Research and Related Training in South Africa*. 2009. ASSAf. Cape Town
[172] Gray A, Vawda Y. Health Legislation and Policy, In: Rispel LC, Padarath A, editors. *South African Health Review 2018*. Durban: Health Systems Trust; 2018. Available at www.hst.org.za
[173] Mouton, J., et al. 2019. *The State of the South African Research Enterprise. DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy*, CREST/SciSTIP. Stellenbosch University 2019.

v. The number of staff with PhDs in the Health Sciences almost doubled from 405 in 2002 to 782 in 2015; and
vi. The proportion of South African staff to total staff grew from 91% in 2002 to 95% in 2015.

The graphical illustration by CREST, at figure 4.12 below, is an important one as it shows the significance of the increased NRF funding in progressively shifting the researcher demographics. Clearly, much more needs to be done for this researcher profile to reflect South Africa's national demographics.

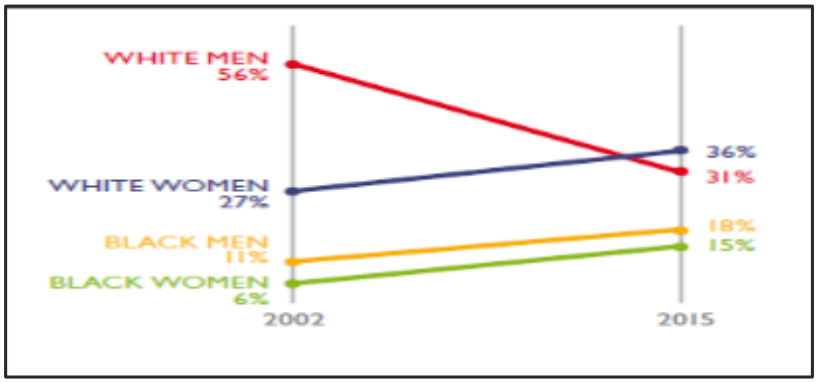


Figure 4.12: Health Sciences: % unique grantholders by gender and race, 2002 & 2015[174]

Furthermore, the CREST study provides a strong output/performance profile in terms of scientific publications over the period 2000 to 2016. Table 4.8 below illustrates the health research enterprise as it exists across the higher education sector and science councils.

2000–2015 Publications above 3000		2000–2015 Publications below 3000	
Public, environmental and occupational health	4 457	Virology	1 768
Infectious diseases	4 414	Neurosciences and neurology	1 706
General and internal medicine	3 607	Surgery	1 635
Pharmacology and pharmacy	3 505	Medicinal chemistry	1 449
Biochemistry and molecular biology	3 481	Respiratory systems	1 401
Immunology	3 457	Psychiatry	1 397
		Cardiovascular system	1 378
		Parasitology and tropical diseases	1 154
		Neuroscience	1 079
		Endocrinology and metabolism	1 060

Table 4.8: Research output/performance profile in the Health Sciences, 2002 and 2016

Broader health sector human resources

In the context of progress with developing and expanding the human resource base in the health system, there have been strong concerns raised. The November 2018 *SA Health Review* opens with the observation in the Editorial Overview that "*Human Resources for Health are the personification of a health system, yet there is relative neglect of, and insufficient investment in the people who work to improve community health and wellbeing*"[175]. Key recommendations call for, amongst other things, enhancing technical capacity and expertise in the NDoH; institutionalisation of a coordinated,

[174] Ibid.
[175] Gray A, Vawda Y. Health Legislation and Policy, In: Rispel LC, Padarath A, editors. *South African Health Review 2018*. Durban: Health Systems Trust; 2018. Available at www.hst.org.za

comprehensive health workforce planning process that is inclusive of engagement with higher education institutions and other stakeholders; urgent and concerted action to strengthen the national health research system as the pursuit of 'universal health coverage requires contextualised scientific knowledge to guide the development of health system-strengthening strategies and interventions' (evidence-based research)[176].

The 2019 National Health Act Guide[177] notes that the NDoH did introduce a focused Human Resources for Health Strategy 2012/13 – 2016/17 for implementation. Of concern is the observation that there was no structured plan for the required actions and the strategy was largely not implemented. The Guide notes that at the time of publication in 2019 there had not been a follow-up revised human resources plan to support to the health strategy.

With regard to human resource development for the health system, it is of particular interest to this report that the National Health Act Guide 2019 draws attention to powers vested in the Minister of Health:

- In consultation with the Minister of Education to establish … *'Academic Health Complexes', which may consist of one or more health establishments at all levels of the national health system, including peripheral facilities, and one or more educational institutions working together to educate and train health care personnel and to conduct research on health services* (Note - As of April 2019 the academic health complexes that exist do so only at the ten central hospitals and do not, as intended in this section, consist of facilities throughout the healthcare system providing a training platform at the various levels of health service provision).

- The Minister of Health must establish a National Health Research Committee tasked with the functions of determining the health research to be carried out by public health authorities; ensuring that the health research agenda and resources focus on priority health problems; development of an integrated health research strategy; and coordination of the research activities of public health authorities.

There are further significant findings in terms of human resources for health systems planning. The 2018 Academy of Science of South Africa (ASSAf) Consensus Report on health professions education had the following findings and recommendations[178]:

- South Africa is renowned for healthcare professional education and training excellence, but this is constrained by fragmentation, weak coordination and poor governance. It was noted that around R12 billion is spent annually in South Africa on health sciences education through multiple fragmented funding streams and departments.

- Public sector academic institutions need to be strengthened to scale up the production of healthcare professionals.

[176] Ibid.

[177] To support access to information and an improved and up-to-date understanding of the legal, regulatory and institutional environment for medical practitioners, private and public health facilities (hospitals and clinics), researchers and students, a detailed and highly comprehensive overview of all matters relating to implementation of the National Health Act is published as a *'National Health Act Guide'* on a regular basis. The most recent publication, 3rd Edition, was published in 2019 by +Section27, a not-for-profit organisation[177].

[178] Academy of Science of South Africa. 2018. South African Consensus Study on Health Professions Education, 2018. ASSAf: Pretoria.

- The clinical training platform should be expanded to include both public and private healthcare facilities and universities should take responsibility for education and professional development from the undergraduate years through to internships and community service.

- The governance of health sciences funding should be enhanced by strengthening the capacity and accelerating the momentum of the Joint Health Science Education Committee.

Clinical research

ASSAf's 2009 Consensus Report on Revitalising Clinical Research in South Africa[179] sought to respond to a suggestion from the private sector, represented by the Pharmaceutical Industry Association of South Africa (PIASA), that there needs to be a stronger awareness amongst authorities of the strong benefits of good scientific clinical research. More specifically, clinical research units should be established at universities, hospitals and research councils to retain research scientists in the country as part of an agenda of building a larger pool of researchers for the future. Reference is made to the powers of the Ministers of Health, and Higher Education, Science and Innovation to establish academic health complexes.

Infrastructure

There are some aspects of the 2018 Presidential Summit report that are specific to technical infrastructure challenges (see the section on Direction-setting and oversight). This includes the observation in the recommendations in respect of the finding of the World Health Organization (WHO) that a well-functioning health system ensures equitable access to essential medical products, vaccines and technologies of assured quality, safety, efficacy and cost-effectiveness, and that these are scientifically sound, and their use is cost-effective. In this regard it can be said that there is a range of institutional restructuring that has been undertaken to facilitate this recommendation. Such institutional restructuring includes the formation of the National Health Laboratory Services (NHLS). The NHLS was established in 2001 with the amalgamation of the former SA Institute for Medical Research, the National Institute for Virology, the National Centre for Occupational Health and the University and Provincial Pathology Laboratories. The NHLS now includes the National Institute for Communicable Diseases (NICD) and the National Institute for Occupational Health (NIOH) as two separate divisions. It also includes the SA Vaccine Producers (SAVP) as a subsidiary.

As observed earlier, a comprehensive study of the role of infrastructure in HESTIIL performance is necessary. However, the infrastructure roadmap report cited before and published under the auspices of the SA-EU Strategic Partnership: The Dialogue facility addressed some of these issues. Although dated, in connection with the Health, Biological and Food Security domain, the study indicated a need for the security of laboratories; genomics/proteomics/metabolomics platforms; and nuclear medicine and medical imaging. These infrastructure gaps remain to be addressed.

Health ICT systems

[179]Academy of Science of South Africa. 2018. *South African Consensus Study on Health Professions Education*, 2018. ASSAf: Pretoria.

The Presidential Summit Report[180] noted that the Electronic Health Record (HER) is an important building block of the NHI but that the current health information system is fragmented with 42 systems and no unified electronic health record. The Report recommended the standardisation of systems using the normative framework for interoperability and for use of information for evidence-based decision-making in health. The Summit also recommended that the existing system be enhanced by improving ICT infrastructure connectivity and the use of ICTs to support data collection and reporting for assessment, screening and intervention programmes.

During the COVID-19 response process, the National Coronavirus Command Council chaired by the President was able to draw on a reconfiguration/repurposing of the electronic geospatial informatics system that the CSIR had developed for the 2010 Soccer World Cup logistics requirements. As a result, the COVID Information Centre was set up at the CSIR to provide close to real-time analytics and dashboards on the Coronavirus outbreak spread across province, district, local municipality and municipal ward. The platform comprises a set of competencies that include epidemiological modelling, data analytics, high-performance computing and data visualisation. This is an exemplary case of the capacity of the scientific research community to respond effectively to a national crisis requiring effective coordination and innovation.

The Health Research Cluster

The health sector does have a 'science council', viz. the South African Medical Research Council (SAMRC). The SAMRC has a legislated mandate to support medical and health research in South Africa, and it reports to the Minister of Health. Other public entities within the executive authority of the Ministry of Health include the National Health Laboratory Services (NHLS) and the newly formed National Public Health Institute of South Africa (NAPHISA). NAPHISA combines the surveillance systems of the NICD, National Institute of Occupational Health (NIOH) and the Cancer Registry to provide coordinated and integrated disease and injury surveillance to enhance the effectiveness of the health system.

There has been significant repurposing of the SAMRC in terms of research activity through the full innovation value chain, including manufacturing. We learnt through the stakeholder interviews that South Africa has the capacity to leverage its expertise in TB diagnostics. However, the full capacity of the system is not being realised, reportedly because of the low level of interest, resource support and policy engagement along the statutory reporting lines. We also learnt that in the absence of effective stewardship from the National Department of Health, the SAMRC successfully forged partnerships across other government departments such as the DSI, and across sectors and science councils.

The university system hosts several world-class research centres, some of which are supported by the DSI-NRF research 'Centre of Excellence' programme. What is most pertinent for this study is the strong integration of different capacities to provide multi- and transdisciplinary expertise for tackling some of the most serious health problems facing the country. These 'centre of excellence' programmes and related research entities include:

- Centre of Excellence for Biomedical Tuberculosis Research (CBTBR) – Universities of Cape Town, Stellenbosch and the Witwatersrand;
- Centre of Excellence in Epidemiological Modelling and Analysis (SACEMA) – Stellenbosch University;

[180] The Presidency: RSA. 2018. Presidential Health Summit 2018: Strengthening the South African Health System towards an Integrated and Unified Health System. Birchwood Conference Centre, Johannesburg, 19-20 October 2018.

- Centre of Excellence in HIV Prevention (CAPRISA) – Universities of KwaZulu-Natal, Cape Town and the Western Cape;
- The Institute of Infectious Diseases and Molecular Medicine (IDM) - University of Cape Town; and
- Wits Reproductive Health and HIV Institute (WHRI) – University of the Witwatersrand.

Furthermore, the University of KwaZulu-Natal's (UKZN) Research and Innovation Sequencing Platform (KRISP) has been created by the coordinated efforts of UKZN, the Technology Innovation Agency (TIA) and the South African Medical Research Council (SAMRC). KRISP is a gene-sequencing research organisation based at UKZN. Researchers can plug a virus genetic map into a free software programme designed by international teams from Belgium, Brazil and South Africa's KRISP.

Table 4.9 provides an overview of the diverse range and locations of 39 DSI-NRF 'research chairs' across the medical and health sciences fields at South African universities. The NRF data breaks down the research chairs according to Health Sciences, Medical Sciences, Health and Medical Sciences, Biological Sciences and Chemical Sciences and Engineering Sciences.

Outside of the university-located research centres and institutions, there is also the DSI-NRF laboratory, iThemba LABS, in the Western Cape, that is focused on nuclear medicine and facilities.

The health sector includes a number of stakeholder associations, including:

- South African Society for Clinical Microbiology (including NHLS and private pathology labs);
- Federation of Infectious Diseases Societies of Southern Africa;
- Critical Care Society of Southern Africa;
- South Africa Paediatric Infectious Diseases Society;
- Infection Control Society of SA (inclusive of public and private IPC practitioners); and
- South African Antibiotic Stewardship Programme.

Among the large private healthcare facilities comprising hospitals, clinics and laboratories are:

- Life Healthcare Group;
- Netcare;
- Lancet Laboratories;
- Ampath Laboratories;
- Clinic; and
- MediClinic Southern Africa.

Some of the larger, more well-known, manufacturing enterprises that underpin the provision of medical and healthcare services include:

- Adcock Ingram;
- Aspen Pharmacare Holdings Ltd.;
- Bayer (Pty) Ltd.;
- Meyerzall Laboratories (Pty) Ltd.;
- Novartis SA and Sandoz;
- Pfizer South Africa;
- SanofI Aventis (Pty) Ltd.;
- Synexa Life Sciences; and
- Thebe Medicare.

Health Sciences	Medical Sciences	Health & Medical Sciences	Biological Sciences	Chemical Science and *Engineering Sciences
NWU: Early detection and prevention of cardiovascular disease in Africa **Wits:** HIV Vaccine Translational Research **Wits:** Health Policy and Systems **UWC:** Bioinformatics and Public Health **UWC:** Health Systems, complexity and social change **UWC:** Microbial genomics **UCT:** Health and Welfare in South Africa **SU:** Mycobactomics **SU:** Mechanistic modelling of health and epidemiology **SU:** Biomarkers for tuberculosis	**UP:** Sustainable Malaria Control **Wits:** Vaccine Preventable Diseases **Wits:** Pharmaceutical Biomaterials and Polymer-engineered Drug-delivery technology **Wits:** Medical Entomology and Vector Control **UCT:** Cancer Biotechnology **UCT:** Immunology and Infectious Diseases in Africa **UCT:** Drug Discovery **UCT:** Vaccinology **UCT:** Clinical Neurosciences Research **UCT:** Brain imaging **UCT:** Poverty-related diseases **SU:** Post-traumatic stress disorder **UKZN:** Systems Biology of HIV/AIDS	**UJ:** Laser applications in health **Wits:** Virus-host dynamics for public health **UWC:** Health systems governance **UCT:** Biomedical Engineering and Innovation **UCT:** Dermatology and Toxicology **SU:** Paediatric Tuberculosis **RU:** Molecular and Cellular Biology of Eukaryotic Stress Response **UKZN:** Antibiotic Resistance and 'One Health' **UFS:** Vector-borne and Zoonotic Pathogens	**Wits:** Protein Biochemistry and Structural Biology **SU:** Integrative skeletal muscle physiology, Biology and Biotechnology **UKZN:** Proteolysis in Homeostasis, Health and Disease	**Tshwane:** Enabled environments for assisted living **UCT:** *Bioprocess Engineering **RU:** Medical Chemistry and Nanotechnology **CUT:** Medical Product Development

Table 4.9: DSI-NRF Research Chairs in the Medical and Health Sciences

Case study on applications of cutting-edge technology in the Health and Well-being sector: Nuclear Technology Products and Services (NTPS)

The Health and Well-being sector provides opportunities for the application of innovations from a number of different disciplines as shown in Table 4.9. The NTPS offers a positive case study on how a South African firm used its capabilities in nuclear science and technology to develop immense market opportunities globally in medical applications.

CASE STUDY 3: NUCLEAR TECHNOLOGY PRODUCTS AND SERVICES (NTP)

South Africa owns and operates three nuclear reactors – research reactor SAFARI-1 [South African Fundamental Atomic Research Installation] and two nuclear power reactors (Koeberg 1 and Koeberg 2). The Nuclear Energy Corporation of South Africa (NECSA) is the custodian of nuclear science. NECSA subsidiary companies include Pelchem and Nuclear Technology Products (NTP). Pelchem supplies value-added products to the electronic, pharmaceutical and petrochemical industries. NTP produces high-quality radiation-based products and services for customers in over 50 countries. The NTP Group is "one of the leading global manufacturers and suppliers of nuclear technology-based products and services for the healthcare, life sciences and industrial sectors".[28]

Historical context: NTP dates back to the late 1940s when South Africa's nuclear research and technology programme resulted in the conceptualisation of SAFARI-1, the country's first nuclear reactor. Although SAFARI-1 was intended for R&D, it showed potential for applications in medical diagnostic devices and treatment procedures through the discovery of 'fission isotope technology'.[29] The discovery led to the establishment of a processing facility in Pelindaba in 1997 that later exported products to an international market and locally produced 90% of all radiopharmaceuticals. To secure a commercially viable enterprise, a commercialisation plan was implemented that would strategically position the organisation to build a large-scale production plant that would be the key exporter of medical radioisotope molybdenum-99. The plan would also repurpose hot-cell complexes designed to test fuel assemblies used at Koeberg's nuclear power facility. Within a 15-year period, NTP succeeded in developing services and products for its clients in nuclear medicine, non-destructive testing, gamma sterilisation, and domestic and international freight forwarding.

Success: A decade later, the commercialisation plan had secured a sustainable nuclear physics and medicine industry and SAFARI-1 programme. With the increased demand for molybdenum-99 and new technologies being developed, revenue growth is expected to reach R2 billion by 2021. Since inception, the organisation went from creating 30 jobs to over 400. It also achieved an annual turnover of over R1,2 billion and developed an international clientele base of over 50 countries.

Strategic intent and products: NECSA undertakes "nuclear research and development".[30] The NTP processes, markets and "all the SAFARI-1 irradiated products and the reactor have become strategically important for the business".[31] NTP products and services include radiopharmaceuticals,[32] irradiation services,[33] radio chemicals[34] and radioactive sealed sources for industry.[35]

Linkages: The NTP has "partnerships with leading academic hospitals and research institutions in South Africa, providing knowledge and technical assistance, as well as supporting clinical trials".[36] Equally important has been the partnership between NTP and National Research Foundation (NRF) iThemba LABS.[37] The NTP also works closely with the International Atomic Energy Agency, which plays an important role in "supporting the sustainable and safe operation of research reactors…"[38]

Research and development: Research objectives and successes:

- The nuclear research technology programme and construction of SAFARI-1 nuclear reactor;[39] and,
- The production of radioisotopes, medical isotopes and radiation products.

Foreign direct investment: From 2009 to 2010, NECSA/NTP earned foreign exchange amounting to R625 million, exceeding its sales target by 21%. Mo-99 and Iodine-131 have become NECSA's main sources of external revenue and profitability. In 2010, NTP Group sales amounted to R795 million, 46% more than estimated, which resulted in the group becoming the world leader in the supply of medical isotopes.[40] NECSA/NTP successes "continued into 2011 when the group's sales amounted to R869 million as other reactors started production".[41] However, in 2012, NECSA/NTP experienced a reversal of fortunes caused by aggressive efforts by competitors to regain market share. This was aggravated by the decline in the global demand for Mo-99 and the global financial crises.[42]

Global expansion and leadership: NTP became a leading global producer of Mo-99 used for the treatment of cancer and heart diseases. In 2000, NTP became the sole distributer of Mo-99. South Africa is the only country to produce Mo-99 on an industrial scale.[43] In 2010, "the IAEA recognised SAFARI-1 as one of the world's major five isotope producers".[44]

Nuclear energy and policy: The Nuclear Energy Act 46 of 1999 provides for the establishment of NECSA as the successor of the South African Atomic Energy Board. The National Nuclear Energy Policy represents the "South African government's vision for the development of an extensive nuclear energy programme".[45] In 2011, the government adopted the Integrated Resources Plan (IRP), which paved the way for the expansion of the country's nuclear power generation capacity. South Africa associates itself with "positive nuclear norms and identities…that is, nuclear not for war purposes".[46]

Challenges: In 2017 the National Nuclear Regulator (NNR) shut down NTP's operations for a year due to safety-related issues. Together with challenges in rebuilding customer relations and safety concerns, this resulted in a major financial loss for the company. Operations resumed in 2018. Current challenges have had ripple effects on its financial sustainability and research, development and commercialisation. Pelchem has equally struggled due to loss of critical engineering capacity and outdated infrastructure.

Lessons:

- The successful conversion of nuclear technology became a major windfall and earned South Africa international recognition from the IAEA.[47]
- By 2010, NECSA/NTP had become the world's first and only company to produce the medical isotope Mo-99 on a commercial scale.[48]
- SAFARI-1's conversion added 'nuclear leverage' to South Africa's nuclear diplomacy.[49]
- NECSA and NTP achieved innovator[50] status in the nuclear medicine field.
- NECSA and NTP played an important role in the promotion of scientific diplomacy between the Global North and Global South.
- Gains made in nuclear medicine can be wiped out overnight if it is established that there is inadequate attention to safety concerns. Ensuring that the right management is in place with the right capacity and focus is essential if a viable commercial enterprise and global stature is to be sustained.

[28] NTP/ NECSA, Global Manufacturer and supply of Nuclear Technology products and Services in http://necsa.coza
[29] Tillwick, DL et al, Operational and Maintenance at SAFARI-1 Research Reactor in South Africa
[30] Seals, H.E The evaluation of the Selected on Site location for a new Nuclear Facility on a Multi-Facility site , International Atomic Energy Agency
[31] Tillwick, DL et al, Operational and Maintenance at SAFARI-1 Research Reactor in South Africa
[32] South African Council for the Non-Proliferation of Weapons of Mass Destruction (NPC), 2011. National Policy on Non-Proliferation, Disarmament and arms control. Available at http://the dti.gov.za/non-proliferation policy/htm.
[33] South African Council for the Non-Proliferation of Weapons of Mass Destruction (NPC), 2011. National Policy on Non-Proliferation, Disarmament and arms control. Available at http://the dti.gov.za/non-proliferation policy/htm.
[34] South African Council for the Non-Proliferation of Weapons of Mass Destruction (NPC), 2011. National Policy on Non-Proliferation, Disarmament and arms control. Available at http://the dti.gov.za/non-proliferation policy/htm.
[35] South African Council for the Non-Proliferation of Weapons of Mass Destruction (NPC), 2011. National Policy on Non-Proliferation, Disarmament and arms control. Available at http://the dti.gov.za/non-proliferation policy/htm.
[36] NTP. Research partnerships in http://ntp.co.za
[37] NTP. Research partnerships in http:ntp.co.za
[38] NTP. Research partnerships in http:ntp.co.za
[39] NTP. Anchoring Africa's Nuclear Technology in http: ntp.co.za
[40] NECSA 2010 cited by van Wyk
[41] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[42] ibid.
[43] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[44] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[45] Department of Minerals and energy (DME), 2008 Nuclear Energy Policy for the Republic of South Africa Available at http://www.dme.gov
[46] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[47] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[48] NECSA World Nuclear News 2010, South Africa's NTP eyes US Isotope Market, 14 April 2010 available at https:/ www./worldnuclearnews.org/news articles'
[49] van Wyk, Jo-Ansie South Africa's SAFARI From Nuclear Weapons to Nuclear medicine in AISA Africa Insight Journal 43(2)
[50] NECSA World Nuclear News 2010, South Africa's NTP eyes US Isotope Market, 14 April 2010 available at https://www. worldnuclearnews.org/news articles'

4.3.1.4 R&D direction-setting and governance

While the National Department of Health (NDoH) carries the overall responsibility for the mandate of the medical and healthcare portfolio, there are four other government departments that are also critical to the development and performance of the health sector. These are the Department of Higher Education and Training (DHET), Department of Science and Innovation (DSI), Department of Social Development (DSD) and Department of Trade, Industry and Competition (DTIC).

The NDoH 2015–2020 National Health Strategic Plan[181] recognises that the South African health sector faces significant and important challenges that arise from a nation that suffers a complex, quadruple burden of disease, an ineffective and inefficient health system, and spiralling private healthcare costs. The quadruple burden of disease includes the HIV/AIDS epidemic, tuberculosis, high maternal and child mortality, high levels of violence and injuries, a growing burden of non-communicable diseases (and other communicable diseases now including COVID-19).

The National Health Research Committee (NHRC) has a legislated mandate to set the research priorities for South Africa. From the work of the NHRC it is noted that the 2018 National Health Research Summit Report[182] details the key recommendations that came from a diverse range of stakeholders, including the research community, government, science councils, the private sector and civil society. An important objective of the Health Research Summit is to assess priorities that are inclusive of issues of 'the social determinants of health' and not just the 'burden of disease'. Social determinants of health include basic services such as access to primary health care, basic income, housing, clean drinking water, safe sanitation, electricity and education.

It is cause for concern that two years later, the recommendations from the National Health Research Committee 2018 summit are quite similar to those priorities identified in the 2015–2020 National Health Strategic Plan, which include the following thematic areas:

- Prioritisation of the 'social determinants of health' and the 'burden of disease' for funding;
- Building capacity of health human resources, along a pipeline, and in line with national transformation imperatives;
- Improving health research funding flows and quantification;
- Creating a national system of health research with a national-provincial alignment of mandates;
- Creating an evidence-based system of health research information management through collation, monitoring, evaluation and translation of health research; and
- Improving the provision of and access to health research infrastructure, especially in academic health complexes.

When it comes to setting the strategic framework, the NDOH and stakeholders are certainly active and demonstrate strong vision in terms of what needs to be done and how science and technology offers benefits to rapidly transform and efficiently accelerate delivery of services. However, implementation seems to lag well behind the shared vision.

[181] National Department of Health. 2015. *The National health Strategic Plan: A long and healthy life for all*. NDoH Pretoria.
[182] Madela-Mntla EN, Ally MM, Hawkridge A, et al. *2018 National health Research Summit Report: Research for Health*. National Department of Health, Pretoria, 2018. Available www.nhrc.gov.za

4.3.1.5 Key issues identified in the Review

(a) In terms of published research outputs and the range of research chairs at universities and other non-profit organisations, the medical and health system appears to be flourishing. Evidence suggests that these research outputs are not finding traction in the development, through the innovation value chain, of a robust healthcare system. The NDoH needs to become far more active in the implementation of the medical and health research agenda, and the downstream applications of the science and technology outputs.

(b) Human resources and technical infrastructure need to be expanded, particularly with respect to innovation for health information management, rapid diagnostics and improved therapeutics, local production of vaccines, critical medicine supplies and the use of precision medicines.

(c) There is a need to act on the findings of science reviews with respect to the provision of stronger support for clinical research.

4.3.2 ICT and the Digital Industrial Revolution

4.3.2.1 Socio-economic development context

The Digital Industrial Revolution (DIR) or Fourth Industrial Revolution (4IR) has applications in a number of diverse areas. For the purpose of this analysis, we will address the HESTIIL capacity issues in terms of the ICT sector in one section, and then the Manufacturing and the DIR sector in another. The NACI Foresight Report 2019[183] also addresses these disciplines under **ICTs and Smart Systems** in one domain/thrust area and **High-Tech Industrialisation** in another domain/thrust area.

The impact of information and communication technologies (ICT) in everyday life, and particularly in so far as health and wealth creation are concerned, has become as entrenched as the use of electricity is to modern society. This thinking has also been expressed in the ICT Research, Development and Innovation (RDI) Roadmap (ICT-RDI) approved by the South African Cabinet in 2013. Just a year before this, the NDP Vision 2030 had called for improved structures in government to manage the ICT environment. The overall objectives of the ICT-RDI Roadmap include collaborative planning on ICT, universal access to ICT, the development of e-government and pro-poor ICT policies, and the positioning of South Africa to benefit from the DIR. The DIR is also referred to as the Fourth Industrial Revolution (4IR).

Countries across the world have moved very rapidly to harness the disruptive and catalytic power of the DIR to drive growth of new industries, create employment and to establish impressive capabilities in improving and speeding up healthcare services, education, transport logistics, agriculture and environmental management, tourism, and general government administration and service delivery, among many other applications. Closing the digital divide is one of the most important and urgent measures that South Africa needs to achieve to address inequality. For when this is accomplished, economic opportunities may be extended to the poor and the marginalised people.

[183] National Advisory Council on Innovation. 2019. *South Africa Foresight Exercise for Science, Technology and Innovation 2030. Innovation for a better Future*. Synthesis Report. NACI. Pretoria.

4.3.2.2 RDI investment in ICT

There is already considerable ICT research and experimental development taking place within the university and business sectors. It is significant that during the financial and economic crises that have endured throughout the world during the first two decades of the 21st century, South Africa has benefited tremendously from a strong financial sector. This may be largely due to South Africa's resolute financial and fiscal regulatory environment for its banking sector. It is also likely due to the electronic sophistication of the banking sector.

The breakdown of ICT RDI investments by sector is shown in Figure 4.13.

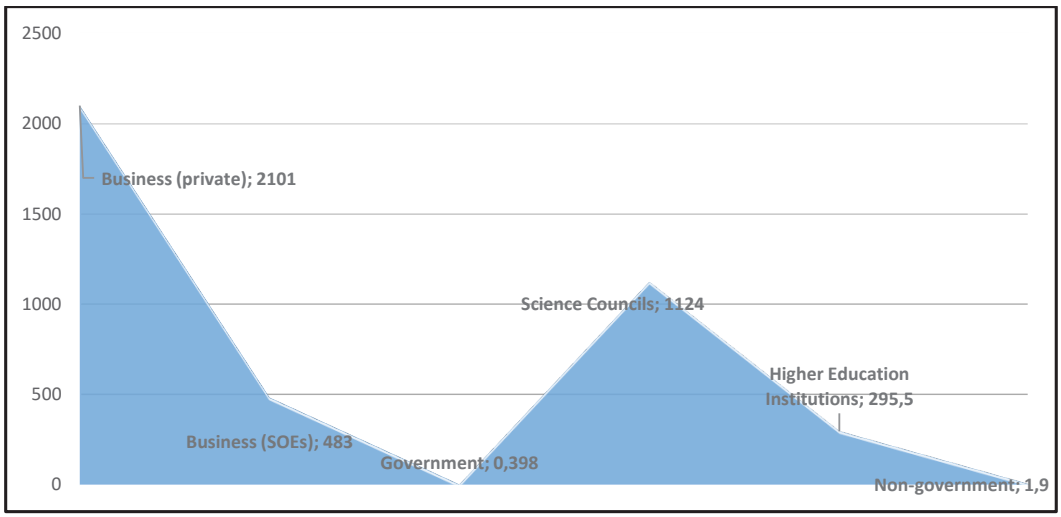


Figure 4.13: ICT investment in RDI 2017/18 (Rm)[184]

South Africa has also demonstrated world leadership in the development of electronic systems for prepaid service systems such as electricity and mobile telecommunications. However, the sterling contribution by the private sector has not been matched by government. For 2017/18, government expenditure on research and experimental development in ICT was a disappointing R398 000 which compares to the private sector contribution of over R2 billion. Although government funds are also reflected in allocations to the universities and science councils, these low expenditure levels are a cause for concern. There are several areas of need that demand far higher capitalisation from government, such as the recent pension grants and COVID-19 social relief disbursement fiasco; the extensive outsourcing of troubled data systems such as that of the Companies and Intellectual Property Commission (CIPC); earlier problems with encryption technologies for identification and passport documents; the multiple failures in relation to geospatial assessments in land ownership; and the environmental and agricultural needs for strengthened spatial data analysis capacity. The urgent need for increased government investment is also applicable to the warehousing and management of access to very large volumes of data that are both structured and unstructured that enter the system at such velocity that traditional systems just cannot manage – described as 'Big

[184] HSRC-CeSTII, 2016/17. *South African National Survey of Research and Experimental Development, Statistical Report 2016/17.* Produced by the Centre for Science, Technology and Innovation Indicators (CeSTII) on behalf of the Department of Science and Technology. Published October 2018.

Data'[185]. The advent of the Square Kilometre Array (SKA) programme elevates even further the urgency of action on this matter.

Figure 4.14 shows the profile of research and experimental development expenditure in ICTs in South Africa for the past ten years[186]. The ICT statistics are presented across private business, state-owned enterprises (SOEs), science councils (SCs), higher education institutions (HEIs), government and not-for-profit organisations (NPOs). The consistently low investment by government is once more noticeable as is the very low but growing expenditure by higher education institutions. The increasing investment registered by the science councils is largely focused on infrastructure and less on the operational costs of research activity.

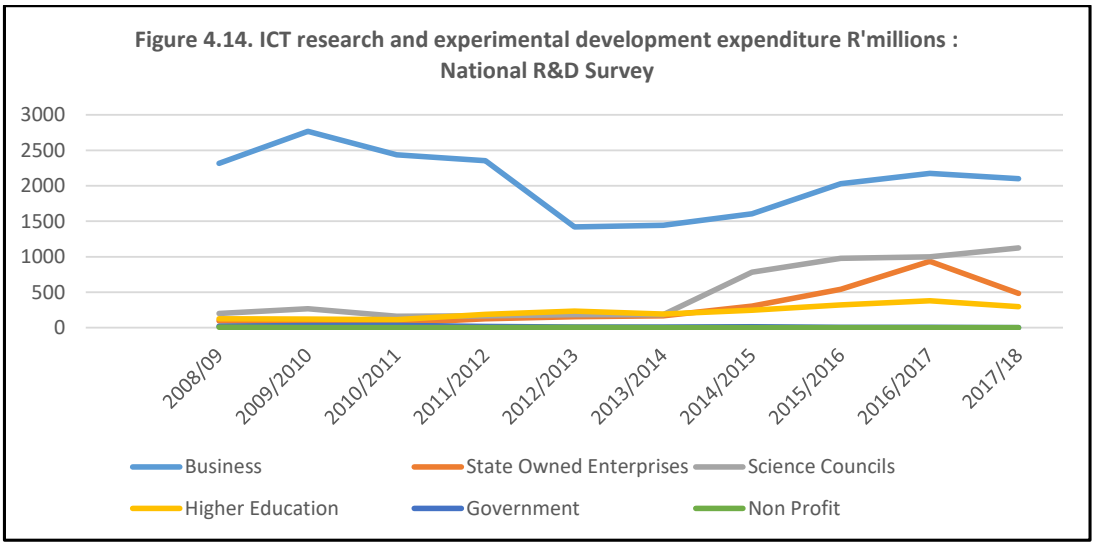


Figure 4.14: ICT research and experimental development expenditure (R'millions) 2008/09 – 2017/18[187]

While economically sound and more sustainable for the private sector to invest heavily in technologies that are innovative and that provide a competitive advantage, the lopsided expenditure ratio is indicative of absolute underspending by government.

If the expenditure of the business sector (private and SOEs) is ignored, then the expenditure trends show that investment appears to be concentrated within the science councils and higher education institutional segments, with high growth recorded in the instance of the science councils in the past three years. The latter is mainly vested in the newly formed SANSA as well as the CSIR. The CSIR hosts a number of the major cyber-infrastructure components:

- Centre for High Performance Computing (CHPC);
- South African Research Network (SANREN);

[185] Gartner's definition of Big Data in terms of variety, volume and velocity.
[186] HSRC-CeSTII, 2016/17. *South African National Survey of Research and Experimental Development, Statistical Report 2016/17.* Produced by the Centre for Science, Technology and Innovation Indicators (CeSTII) on behalf of the Department of Science and Technology. Published October 2018.
[187] Ibid.

- Data Intensive Research Initiative of South Africa (DIRISA);
- Centre for Artificial Intelligence Research (CAIR);
- National Laser Centre;
- the component for analysis of satellite-sourced data; and,
- the component for encryption technologies.

When discounting the capital expenditure for these entities, what remains is the CSIR's Meraka Institute as its main R&D performer. Even then, within the CSIR, the ICT research activities and investments are relatively small and fragmented.

4.3.2.3 The ICT research base

In order to have a far more granular understanding of investments in ICT research capacity, a detailed study is recommended. Nonetheless, the aggregate investments in both open source and broader ICT reflect large investments in infrastructure, and it is not clear how much of this investment went towards ICT researcher costs. Researcher FTE numbers are a cause for concern, particularly if one looks at the trends in government and science councils where the focus is on supporting innovation for modernisation and competitiveness. Figure 4.15 shows that, with the exception of universities, the number of researchers in the ICT domains has remained stagnant in the public sector and science councils.

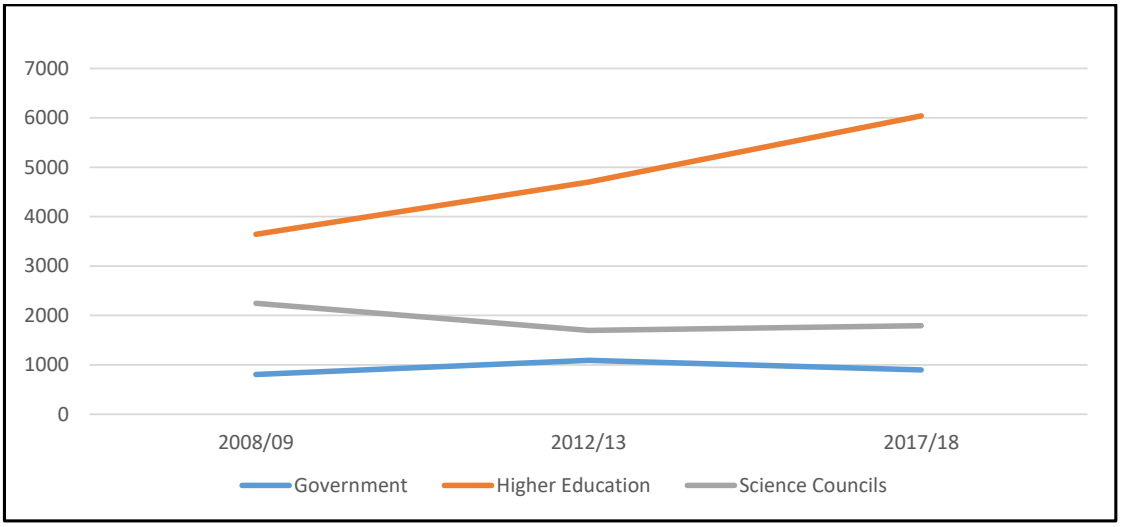


Figure 4.15: FTE researchers (excluding postgrads) 2008/09 – 2017/18[188]

Researchers

The NACI Foresight Synthesis Report of 2019[189] observes that South Africa performed very well amongst the BRICS countries over the period 2008–2018 in terms of number of publications in the ICT domain. This is in terms of both per capita and per size of the population. In terms of quality of the publications the finding was not as favourable. The observation is that there are no disciplines relevant

[188] Source: National R&D Survey 2017/18.
[189] Ibid.

to the ICT domain for which the degree of specialisation and the quality of publications are both high. These challenges exist despite the ambitions of NDP 2030 and the ICT Roadmap.

This assessment of ICT applications as it relates to specific disciplines is a critical one. The investments in research, development and innovation in ICT is generally directed at achieving process and product changes, efficiencies or analytical results faster or easier. It has benefits for the operations of business, government, the research community and ordinary citizens across all spheres of daily life.

ICT R&D infrastructure

When turning to ICT research, development and innovation capacity in South Africa, the picture is less clear, and it does suggest the absence of a coherent, well-directed national effort. The response to the COVID-19 pandemic provided an opportunity to demonstrate the value of the country's ICT systems. The information systems (infrastructure and researcher capacity) were rapidly repurposed off platforms that had been developed for the 2010 Soccer World Cup by the CSIR for data gathering, monitoring and analytics (modelling). The science behind the data-modelling capability in conjunction with high-performance computing has proven particularly relevant in so far as the interface between patients and the healthcare system (private and public sectors) is concerned. However, this has demonstrated only the country's agility in repurposing existing platforms and does not reflect adequate scientific research capacity and the associated infrastructure.

Recently, the DSI has considerably augmented investments in ICT infrastructure and collaboration across government with the establishment of the Centre for Artificial Intelligence Research (CAIR), the National Integrated Cyber-Infrastructure System (NICIS) and the Data-Intensive Research Initiative of South Africa (DIRISA). DIRISA, with a focus on Big Data, adds to the capabilities built up with the Centre for High-Performance Computing (CHPC), the South African National Research Network (SANREN) and the Meraka Institute. All of these were established by the CSIR on behalf of the DSI with ring-fenced funding and they still operate as separate programmes within the CSIR. This is in line with the 2013 ICT-RDI Roadmap that pitched for a 'Portfolio Management' arrangement between DST and the CSIR's Meraka Institute. Whether this set-up within the CSIR is optimal for effectively addressing the objectives of the 2019 STI-WP is further explored in this report. In the final analysis, the Review Panel is not convinced that there is capacity to drive one coherent, nationally coordinated programme of ICT R&D based on the cyber-infrastructure located at the CSIR.

It does not inspire confidence to see discrete initiatives that are scattered and sometimes duplicated across many different institutions. This low-intensity, fragmented investment may be reasonable for catalysing new or emerging research areas and for seeding the start-up of research platforms locally. However, these initiatives should be followed up by a scaling-up process to develop critical mass, particularly when the activity demonstrates some promise in terms of research excellence. This is an important consideration in that the main arguments for increasing government R&D investment are building human capital and technical competitiveness for the economy.

The past ten years have largely been marked by regulatory sluggishness and institutional incompetence that impeded South Africa's opportunities to benefit from the digital dividend, i.e. the migration from analogue to digital. Had this been undertaken expeditiously, it could have led to efficiencies and lower costs, more technology convergence and access. Nevertheless, the past decade has also been a period of dramatic change in the technology ecosystem of the ICT sector. This has included the introduction of high-speed 4G technology including LTE, the landing of an additional five undersea cables following on the pre-2009 Telkom South Atlantic 3 (SAT 3) infrastructure, and more recently the first stages of 5G technology investment.

4.3.2.4 Research direction-setting and governance

In 2019, the President of the Republic restructured and resized Cabinet and among other things combined the Departments of Communications and Telecommunications and Postal Services under one ministry. The result was the establishment of the Department of Communications and Digital Technologies (DCDT). According to the government website, the mission of the new DCDT is to create an enabling environment for the provision of inclusive communication services to all South Africans. This would be undertaken in a manner that promotes socio-economic development and investment through broadcasting, new media, print media and other new technologies, and to brand the country locally and internationally.

The Department's strategic outcome-orientated goals are to:

- Enable the maximisation of investment in the ICT sector and create new competitive business opportunities for the growth of the ICT industry for socio-economic development;
- Ensure that ICT infrastructure is accessible, robust, reliable, affordable and secure to meet the needs of the country and its people;
- Accelerate the socio-economic development of South Africans and facilitate the building of an inclusive information society through partnerships with business and civil society, and the three spheres of government;
- Improve departmental performance and enhance the role of ICT state-owned enterprises (SOEs) as the delivery arms of government; and
- Contribute to the global ICT agenda prioritising Africa's development.

To give effect to its mandate, the DCDT has oversight responsibility for the following entities/infrastructures/national assets:

Reporting entities

- .za Domain Name Authority (ZADNA);
- Broadband Infraco;
- Film and Publication Board (FPB);
- Independent Communications Authority of South Africa (ICASA);
- National Electronic Media Institute of South Africa (NEMISA);
- Sentech;
- South African Broadcasting Corporation SOC Limited (SABC);
- South African Post Office (SAPO);
- State Information Technology Agency (SITA);
- Telkom; and
- Universal Service and Access Agency of South Africa (USAASA).

Policy and strategy

The 2017 National e-Strategy builds off the policy direction in the ICT White Paper and positions the key objective in terms of driving well-coordinated national efforts: *Towards a thriving and inclusive future*. The White Paper calls for the establishment of a National e-Skills Institute and for the Department of Science and Innovation to establish a targeted Digital Transformation R&D Programme that will be driven across government departments. The National e-Strategy states that both the Integrated ICT Policy White Paper and the ICT RDI Roadmap, led by the DSI, identify massification of skills as one of the priorities of the ICT sector and asserts that the National Electronic Media Institute of South Africa (NEMISA) will be transformed into a fully-fledged National e-Skills Institute to drive the

development of e-skills in society. NEMISA currently offers a range of mainly one-year certificate programmes at the NQF 3 and NQF 4 levels for matriculants interested in careers in animation and visual effects, design techniques, interactive media, radio production, film and television production operations.

Of some note is that the e-Strategy assigns responsibility for research, development and innovation to the Department of Science and Technology (now DSI) under a Working Group platform that reports to the Digital Transformation Committee headed by the DCDT (previously the Department of Communications). It is worth considering that the DSI may not have fully seized its responsibilities within this platform. Now, in 2020, events have overtaken the 2017 arrangements. For example, in his State of the Nation Address, the President announced that a new university will be established in the Ekurhuleni metropolitan area. The Minister of Higher Education, Science and Innovation provided more detail on the role of the new university: it could produce cutting-edge science and technology innovations across crucial areas such as data science, machine learning, artificial intelligence, block chain, robotics, hydrogen-powered technologies, smart transportation and logistics systems.

The Report of the 4IR Presidential Commission draws attention right at the outset to the absence of a single-minded ICT focus: *'South Africa currently has different elements of the 4IR spread across Government, the private sector and civil society but there is no single plan or blueprint which brings together all role players into a single focus'*. It is argued that a key aspect that will inform the achievement of such single-mindedness will be institutional capacity considerations.

The STI-WP presents a definition of the Fourth Industrial Revolution as: *'…Integrating cyber-physical systems and the Internet of Things, Big-data and cloud computing, robotics and artificial intelligence (AI) based systems and additive manufacturing…'* The STI-WP specifically calls for expansion of the Centre for AI Research (CAIR) which already has firm linkages with universities, as well as for stronger institutionalisation of 4IR investments by the DSI. The DSI's efforts have focused on shifting to a more integrated approach with the establishment of the National Integrated Cyber-Infrastructure System (NICIS), still based at the CSIR, but it is not evident that this has gone far enough in consolidating and expanding the research enterprise in terms of 4IR.

The most logical response to this challenge therefore is the planned growth of the 'portfolio' to a level that is far larger than anything that is currently in place at the CSIR. As the DSI has already ring-fenced some investments in ICT, there should be little difficulty in consolidating the existing mandates, assets and investments under a single entity. A new institution takes time to establish. This is especially the case if it is to be a national research institution that requires legislation for its establishment. It would therefore be necessary to have a medium-term (three-year) plan and process to manage the transition.

Figure 4.16 maps out some of the key role-players in this cluster.

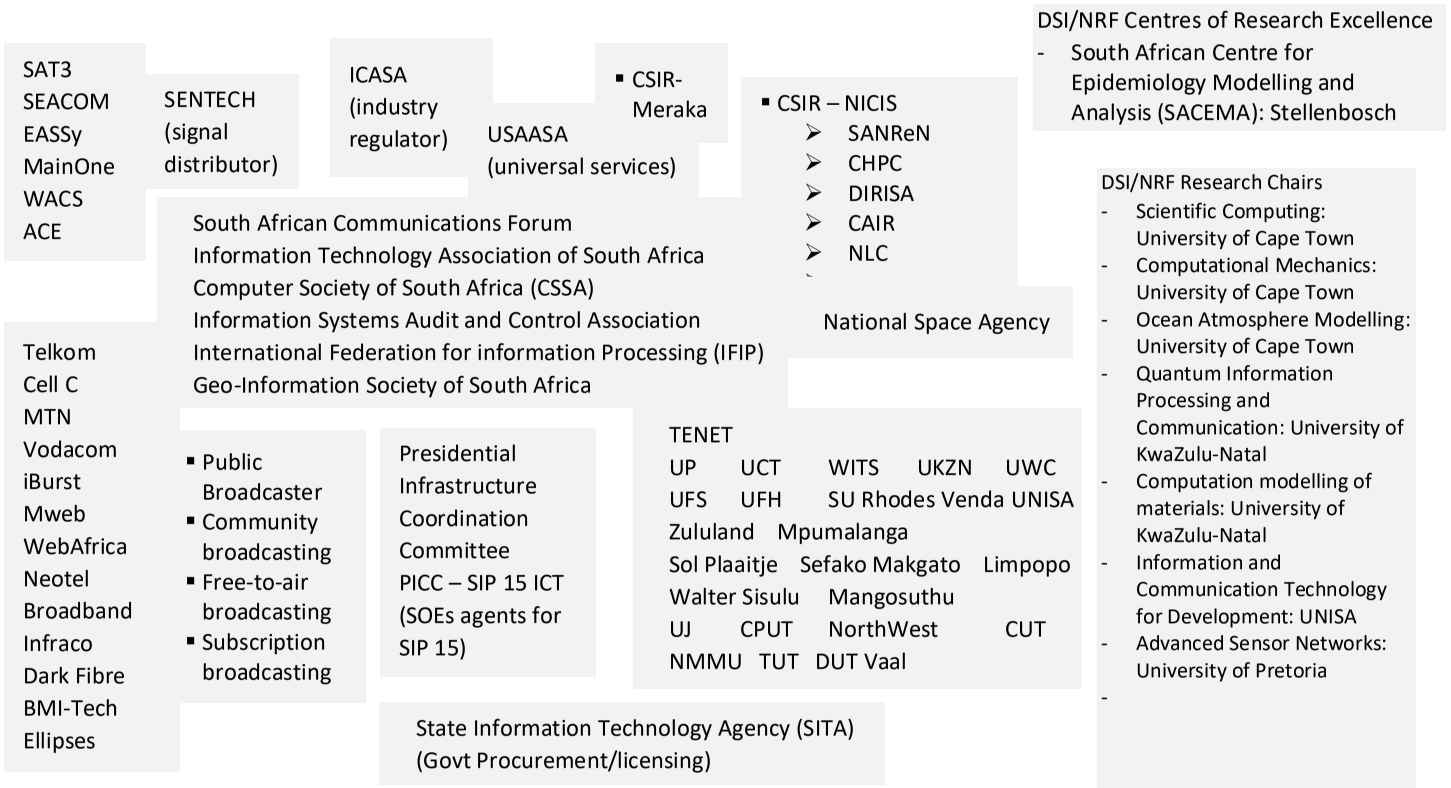


Figure 4.16. Some of the key entities in the ICT institutional landscape

4.3.3 Marine sciences and the oceans economy

4.3.3.1 Socio-economic-environmental context

Much has been written about the fact that South Africa possesses one of the few 'peninsula' geographic positions. The country's national borders are bound by three oceans (Indian to the east, and the Southern and Atlantic to the west). There are a number of government departments with a sectoral responsibility across a range of aspects of what is referred to by government as 'the oceans economy'. These range from custodianship of territorial islands in the Antarctic and administrative compliance with the International Law of the Sea, to fisheries and estuaries management, earth and climate science, and fossil-fuel deposits in the oceans.

There is currently a moratorium on any form of economic, industrial or commercial activity in the Antarctic. South Africa is signatory to the Antarctic Treaty System (ATS), an international agreement which has committed all signatory countries to confine activities in the Antarctic environment (south of 60^{o}S) to peaceful and scientific purposes only. The DEFF on behalf of South Africa has responsibility for the logistical capability to monitor South Africa's Antarctic base and those of Marion and Gough Islands. The only human activity that is encouraged in Antarctica is that of scientific research, which the DSI has been supporting for many decades. In this respect, the two departments formerly known as DST and DEA have a strong record of cooperation. This includes the shared use of the logistic facilities including the research vessels.

South Africa's profiling and steering of the oceans' economy has over the last decade expanded from a narrow (environment and research), fragmented and siloed focus to a robust multi-stakeholder drive for inclusive growth through Operation Phakisa – the Oceans Economy. Operation Phakisa has focused on six areas: (i) oil and gas; (ii) aquaculture; (iii) maritime protection services and ocean governance; (iv) transport and manufacturing; (v) small harbour development; and (vi) coastal and marine tourism and enablers. A sound holistic perspective is advocated also by the South African Maritime Safety Authority (SAMSA) that quite aptly describes South Africa's oceans as the '10th Province'[190]. South Africa currently has a claim before the United Nations Convention on the Law of the Sea (UNCLOS) that will amass a larger exclusive economic zone (EEZ) that extends beyond the mainland that is three times the size of the mainland. This development should drive and shape thinking on the oceans economy. With South Africa potentially controlling such a vast area of ocean assets will come increased and complex responsibilities. This would include the safety of property (vessels) and people at a time when there is rising lawlessness at sea, particularly along the eastern seaboard. SAMSA itself makes considerable investments in surveillance technology, such as the long-range identification and tracking (LTIR) system.

There is likely to be ongoing science-based surveying to defend the country's claim. Even if South Africa receives less than what it claims, there is still a great deal of responsibility that will arise. These would include stewardship/custodianship, sustainability challenges with respect to management of ocean-based resources for economic gain and social development, and the protection and conservation of the integrity of the ocean environment (the so-called 'blue economy').

4.3.3.2 R&D investments in marine sciences

[190] SAMSA, *The 10th Province*. Available https://samsa.blog

It is noted from the National R&D Survey 2017/18 report[191] that research in the marine sciences field has grown by roughly 284% since 2007/08 when it was R50 579 000 to R143 621 000 in 2017/18. Figure 4.17 illustrates the breakdown of RDI investments by sector in the marine sciences. It is concerning that business (both private and state-owned enterprises) have zero investments in this area for 2017/18 and that even over the past ten years it has been negligible compared to that of the science councils, government and the higher education sector.

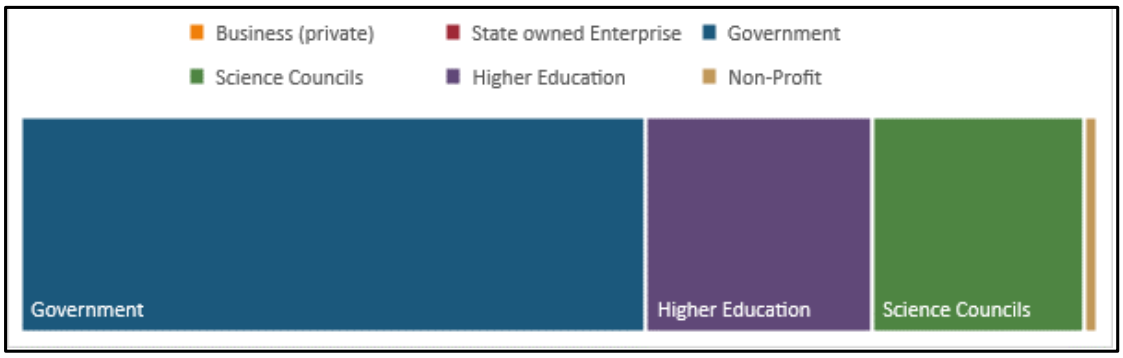


Figure 4.17: Breakdown of R&D expenditure in the marine sciences 2017/18[192]

A closer look (see Figure 4.18) points to a dramatic decline in investments by SOEs in marine sciences. This trend is most peculiar as it came at a time when government had prioritised the oceans economy as a platform for regenerating growth and employment.

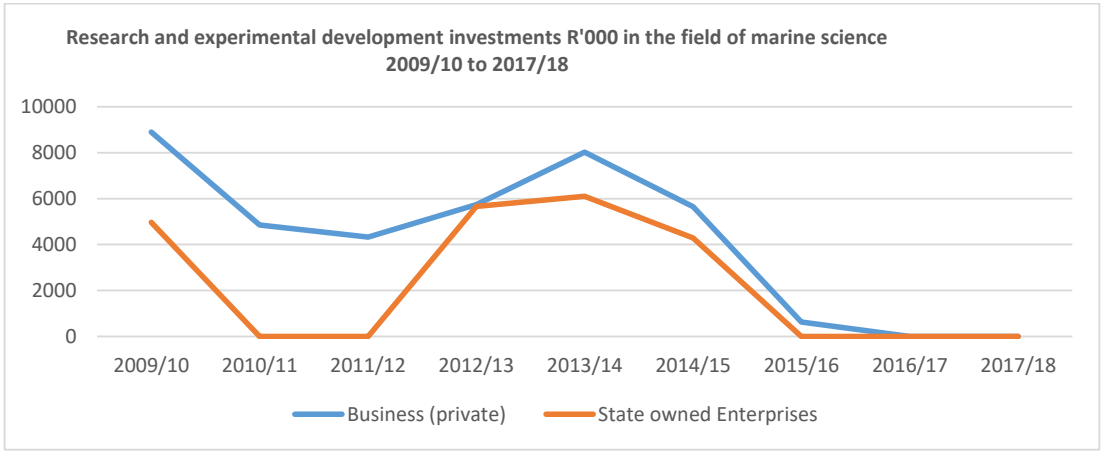


Figure 4.18: R&D investments in marine sciences, R'000 2009/01 – 2017/18

4.3.3.3 The research base

The marine sciences research base comprises many institutional actors with diverse research efforts, some of which date back centuries such as climate science, fisheries research, sea-floor mapping and ocean monitoring.

[191] National R&D Survey 2017/18.
[192] Ibid.

The DSI has a long-standing investment in the South African National Antarctic Research Programme. This is operated through the National Research Foundation (NRF) which supports researchers, primarily from universities. In addition, the DSI through the NRF supports research in the marine sciences through grant funding to rated researchers, investments in infrastructure and large equipment, and through the research chairs and centres of excellence programmes. The Department of Environment, Forestry and Fisheries (DEFF) has control of much of the core infrastructure, research vessels and stations at various ports along the 2 800 km South African coastline. The DEFF also hosts environmental-management and weather-modelling research programmes. The CSIR hosts a significant climate and ocean research programme as does the NRF/South African Institute for Aquatic Biodiversity (SAIAB) with the African Coelacanth Research Programme. There are also strong university-based research centres that are not always funded by government, but which possess international partners and funders.

While universities, particularly those with Centres of Research Excellence and Research Chairs, play a key role in growing the pipeline of human capital, they can never be fully constituted as agencies for government functions, nor can they be expected to provide long-term employment for scientists and engineers in this field. The existence of a plethora of small-scale projects scattered across a few platforms or hidden away in larger organisations, does not inspire confidence that the research enterprise is being taken seriously. If one considers that a number of the initiatives involve long-term monitoring and assessments, and therefore massive volumes of data are collected at great cost, time and effort, then the security of data is a major concern when it is entrusted in an insecure institutional structure.

This points to the need for 'Big Data' infrastructure and a robust institutional platform that provides one portal for all of government funding across the oceans and Antarctic research efforts. Such an institution would be able to facilitate processes to address duplication. Multiple efforts sometimes present healthy competition and alternative insights, but very often waste resources. Such a body should have responsibility for the long-term curation of all ocean- and Antarctic-related scientific research data, particularly those produced from government funding. This body should also have the mandate to conduct large-scale research projects that are usually beyond the scope of individual universities. This is particularly important in the context of possible increased responsibilities for South Africa in the context of an extended EEZ, and the immediacy of the oil and gas industrial exploration and production in the Southern Ocean.

Researchers

The 2016 Marine Research Strategy noted that South Africa has a diverse and active marine science community, with areas of excellence in ecology and ecosystem research, fisheries and marine biodiversity. Active laboratories and researchers exist at several institutions and most of them serve as training facilities as well as research centres. The strategy noted that the major challenge is the lack of coordination. This precipitates the duplication of efforts and scarce resources, and prevents the achievement of synchrony. It is also impossible to determine the number of researchers in this field. As a result, the closest approximation of the number of researchers can be drawn from the statistics of the NRF by aggregating the number of rated researchers across the fields of earth and marine sciences. However, this does result in an over-count as parts of the earth sciences research do not include the marine sciences. Furthermore, researchers are not based only at universities but also include NRF-rated researchers from science councils, other departmental agencies and some non-profit organisations. The list is included as **Annexure B** to this report.

Infrastructure

Government invests in large infrastructures including the refurbishment of the *SANAE IV* and the new *SA Agulhas II* research vessels. The DSI has funded large equipment that includes ocean robotics such as the underwater ROV *Sea-eye Falcon* to explore depths beyond scuba range. It has also funded small vessels such as the *R/V uKwabelana* (Port Elizabeth) that can carry up to 11 scientists, and the *R/V Phakisa* (Durban). With the establishment of the South African National Space Agency, the contributions of satellite-sourced ocean-observation data have strengthened the research enterprise and global research partnerships. In terms of international environmental conventions, the DEFF (previously called the DEA) has the responsibility for logistics management of the research vessels used for the expeditions to Antarctica. DEFF manages access to the *SA Agulhas* and *FRS Algoa* for research purposes and supports some research through one of its agencies, the Sea Fisheries Institute. For purposes of its broader mandate, DEFF operates a small fleet of surveillance and sea fisheries protection vessels. These include the *Ruth First*, *Sarah Baartman*, *Victoria Mxenge* and *Lilian Ngoyi*. In addition, DEFF operates the South African Vessel Monitoring System (VMS). This is a complex system that primarily provides monitoring, control and surveillance in terms of the Marine Living Resources Act, permit conditions and international legislation and agreements covering South Africa's Exclusive Economic Zones (EEZs) as well as other countries on the high seas. The VMS is of significant value to fisheries scientists and marine resource managers.

4.3.3.4 Research direction-setting and governance

The White Paper on the National Environmental Management of the Ocean (NEMO) declared that responsibility for ocean governance would reside within the Economic Cluster of Cabinet. In terms of this agreement, the DSI (as the department mandated to coordinate R&D) will, in partnership with DEFF, the former DAFF (at the time the Department of Agriculture, Forestry and Fisheries) and other stakeholder departments, lead the establishment of a marine and Antarctic research steering committee (MARS Comm) that will be appointed for implementation of the MARS strategy.

Even before the 'game-changing' ocean-based economic prospect came to light, the DST and DEA jointly structured and signed a Marine and Antarctic Research Strategy (MARS) which articulated two key ambitions with regard to South Africa's marine and Antarctic environments. The first, deriving from the 2002 National Research and Development Strategy (NRDS), is to maximise the benefit of the strategic 'geographic advantage' to South African research and science. The second, deriving from the NDP-Vision 2030 and Operation Phakisa, is to increase and maximise the socio-economic benefits derived from the oceans[193].

A closer examination of the NDP reveals that there is a strong call for DSI-directed research support for socio-economic development imperatives and for DEFF environmental monitoring and protection as regards maintaining the health of the oceans and ecosystem services. The big challenges are climate change and the excessive pollution due to human activity. Both key departments, DEFF and DSI, have considerable interests in a coordinated marine sciences programme, including the area of the oceans and ocean resources.

[193] DST and DEA, 2016. *Marine and Antarctic Research Strategy, Version 4.5*, June 2016. Pretoria, DST.

Figure 4.19 shows the impressive but fragmented spread of organisations with activities related to the DST/DEA oceans and Antarctic programmes, and Operation Phakisa, as well as the many university-based and not-for-profit organisations with R&D activities. Naturally, there is a strong representation of the coastal universities – University of Cape Town, Stellenbosch University, University of the Western Cape, University of KwaZulu-Natal, Rhodes University and Nelson Mandela University

RESEARCH INSTITUTIONS (includes ocean surveying)
South African National Antarctic Programme (SANAP) NRF
Oceanographic Research Institute (ORI) – Ushaka
South African Institute for Aquatic Biodiversity (SAIAB)/NRF
South African National Biodiversity Institute (SANBI)
Council for Scientific and Industrial Research (CSIR)
JG Field Marine Research Institute – UCT
International Ocean Institute of South Africa (IOISA) – UWC
Institute for Coastal and Marine Research (CMR) – NMMU
South African International Maritime Research Institute – NMMU
Sea Fisheries Institute – DEA
Institute for Maritime Technology (IMT) – DoD
Petroleum Agency of South Africa

INDUSTRY AND INDUSTRY ASSOCIATIONS
Fishing companies
Boating and tourism companies
Oil and gas exploration companies
PetroSA
Metocean Services International
SA Oil and Gas Alliance

NATIONAL AUTHORITIES (INSTITUTIONS)
South African Maritime Safety Authority

RESEARCH VESSELS
FRS Algoa Coastal RS Ellen Khuzwayo
FRS Africana SA Agulhas

MARINE PROTECTED AREAS
Amatole Offshore
Agulhas Front
Agulhas Back
Aliwal Shoal
Benguela Muds
Browns Bank Corals
Cape Canyon
Childs Bank
Namaqua Fossil Front
Namaqua
iSimangaliso
Port Elizabeth Corals
Uthukela
Orange Shelf Edge
South East Atlantic
Protea
Robbin Island
South West Indian Seamount

GOVERNMENT DEPARTMENTS
Environmental Affairs Tourism
Science & Technology Education
Trade and Industry Transport
Minerals Resources Energy
Defence
International Relations and Cooperation
Provincial governments of MP, KZN, EC, WC and NC.

RESEARCH NETWORKS
Parts of South African Environmental Observation Network (SAEON) - NRF
Benguela Current Large Marine Ecosystem (BCLME) Project
South African Network for Oceanic Research
SA Chapter of the Indian Ocean Rim (OIR) Association Academic Group
South African Association for Marine Biological Research – Ushaka

Figure 4.19: Entities engaged in R&D activity in the oceans' economy

4.3.4 Earth science, climate change and water security

4.3.4.1 Socio-economic context

It is significant that the NDP Vision 2030 specifically calls for the establishment of an Earth Systems Observatory[194]. It is unusual for a consolidated national plan to call for government to set up specific institutions, but such is the seriousness of the impact of drought, concerns for food security, biodiversity loss, pollution, land and resources degradation on sustainable livelihoods for South African society, that a strong national remediation and development drive is required. This area of earth system sciences has already been identified as a key thrust area in the early 2019 NACI Foresight Study. In this review, we take the view that instead of lumping Earth Systems Sciences with Marine Sciences and the Oceans Economy, the former, given its centrality to sustainable livelihoods for example, requires a detailed examination in its own right. Our approach dovetails with government's focus on the climate change impacts on sustainable land use, agriculture and sustainable livelihoods, food security, drought, water security and sustainable ecosystem integrity and environmentally sustainable production and health.

Research on the interplay and tensions between people, planet and economic prosperity has been driven from a few separate reference frames that warrant clear definitions before one can map out what work is currently being done. Within the science and technology community in South Africa use has been made of the terms 'climate change' and 'global change', each having slightly different meanings. This work is guided by the definition provided in a report by ASSAf wherein, conceptually, global change is presumed to be inclusive of climate change. The term 'Earth System Sciences' responds more fully to the global change dynamics and follows an international trend to promote trans-and multi-disciplinary science programmes to address complex problems. A more elaborate discussion of the definitions is found at **Annexure B** to this report.

The 2019 STI-WP reinforces the strategic importance of employing a broader, system-wide focus such as the Grand Challenge programme construct on global change[195] introduced within the 2008–2018 Ten-Year Innovation Plan. An important dynamic to note is that with global change impacts covering so many different economic and resources areas, the focus of scientific research needs to incorporate multi-disciplinary and transdisciplinary areas with coordination across many government departments and institutions. It is important to note that the use of the broader definitions of global change and earth system sciences does not diminish the importance that government attaches to investing in research activities in climate change. The 2019 STI-WP recognises that amongst the many key drivers of global change is the state of the environment, with climate change impacts carrying severe consequences for the most vulnerable members of society. While there are social and behavioural aspects that can mitigate some of the threats related to greenhouse-gas (GHG) emissions and land, air and water pollution, the core threat lies in the nature of the materials we use and the manufacturing processes that are used. In this regard there is a major role for climate change science and technology to provide sustainable technological mitigation and adaptation solutions and alternatives.

The work in this area conducted by ASSAf and others has helped to articulate the linkages between policymakers and the science community. Government planning and implementation is vitally dependent on evidence-based environmental, economic and social risk assessments. The evidence itself must be based on sound science since the negative consequences of bad resources decisions

[194] Ibid.
[195] DST: *10-Year Global Change Research Plan for South Africa*. Available DST website https://wwwdst.gov.za

related to land use, water management and oversight of industrial activity can have catastrophic impacts on society and the economy.

Government decision-making is enhanced by a healthy objective distance between the producers of the evidence and the policy/decision-makers. This is where the importance of research intermediaries comes in, such as the roles of research institutions that can pull together multi- and transdisciplinary research teams from many organisations to produce policy reports on the state of the environment and other such reports. For many years this function on the state of the environment was outsourced, not always to the same institutions, and was further compromised by information gaps in key aspects of environmental conditions. The question of the need for a 'national environmental research institution' was frequently raised. It now comes to the fore again, but this time in the form of calls for a 'national earth systems research institution' such as the earth systems observatory identified in the NDP.

4.3.4.2 Expenditure in earth systems science R&D

Information available from the National R&D Survey puts expenditure in 2017/18 in the broader field of environmental research (as a socio-economic objective) at over R2 billion[196]. This is over 7.3% of gross expenditure on R&D. Figure 4.20 shows the distribution of environmental R&D expenditure in the context of the research vision shaped by the 'socio-economic objective'. Of note is that science councils and universities dominate, with negligible investment by the private sector and SOEs. However, there is little information available on a finer breakdown of what is included in the environment-related sciences.

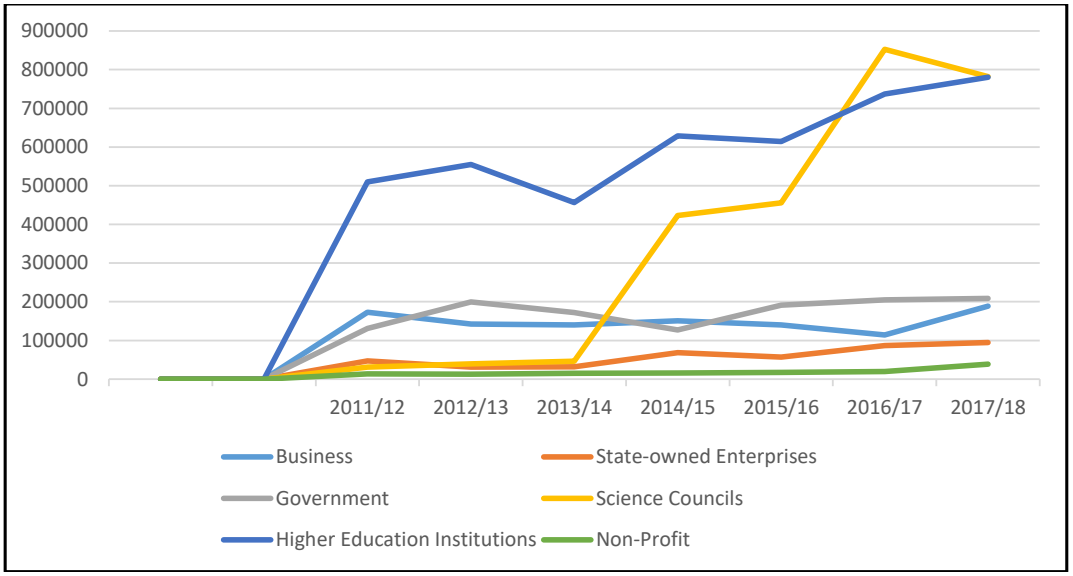


Figure 4.20: R&D expenditure in environmental sciences 2017/18 (R'000)

4.3.4.3 The research base

From the literature available it is noted that the most important aspect of earth system science and its value to decision-makers across government, industry and the broader public is that it is founded on sound science. By its very nature, this research is underpinned by evidence compiled over long

[196] National R&D Survey.

periods of time. Consider for example the natural evidence embedded in sediments, rocks and fossils that pre-date recorded history. The research is data-intensive and draws on a vast array of scientific evidence such as satellite imagery, field-based longitudinal studies, laboratory-based assessments of sediments, climate and environment data, system change simulations and response modelling. As is often indicated in the literature, this research requires highly specialised scientific expertise in multiple disciplines to go back across geological, geo-physical and biological timeframes to map out natural cycles and to identify anthropogenic signatures. This is essential to ensuring that there are solid arguments to inform government of risk and vulnerability profiles across the country related to particular global change trends.

Researchers

There are active laboratories and researchers at several institutions and most of the laboratories serve as training facilities as well as research centres. Access to detailed information on numbers of researchers in this field is not readily available. The data used in the previous section on the marine sciences field covered the broader environmental sciences and so we link the recommendations to the same findings as in the previous section. The closest approximation can be drawn from the statistics of the NRF in terms of rated researchers across the fields of earth and marine sciences. These are detailed in **Annexure B** to this report.

Infrastructure

The DSI/NRF-funded South African Environmental Observation Network (SAEON) was initially established with ring-fenced funding. Its role was to provide support for developing long term *in-situ* environmental observation data. Additionally, it was to provide the technical infrastructure to support collaborative access to the data and information repositories of a vast national network of research groups recognised as SAEON 'nodes'. SAEON later took up responsibility for housing the 'climate change' technology platform of the South African Risk and Vulnerability Atlas (SARVA).

The DST has also established a South African Earth Observation System of Systems (SAEOSS) that is a national component of the Global Earth Observation System of Systems (GEOSS). Care must be exercised in profiling SAEOSS within the earth sciences infrastructure system portfolio. SAEOSS, as a space observation infrastructure platform, is now embedded within the South African National Space Agency (SANSA). It is not designed to undertake scientific research per se, but, operating as an infrastructure platform, it can be used by all scientists and researchers across the local and international community to undertake research.

The ARC has a vast array of climate information/weather stations located on farms across the country whereby data is fed to its Institute for Soil, Climate and Water (ISCW) as well as to the South African Weather Service (SAWS). For purposes of collecting relevant climate and ocean data, the Department of Environment, Forestry and Fisheries (DEFF) spends a considerable amount of money annually on non-retrievable weather buoys located along the coastline.

4.3.4.4 Direction-setting and governance

A good starting point for examining the effectiveness and adequacy of the steering capacity for this cluster is to look at the needs expressed by DEFF. The DEA/DST (now DEFF/DSI) collaboration led to the adoption in June 2012 of the Environmental Sector Research, Development and Evidence (RD&E)

Framework[197]. Five priority areas were identified for immediate implementation, notably biodiversity, waste management, climate change, air quality, and oceans and coasts.

The DSI commissioned ASSAf to draw on its access to a wide range of scientific expertise within its membership to produce a regular assessment of progress on the interface between climate change science and policy in South Africa. In this regard, the *First Biennial Report to Cabinet on the State of Climate Change Science and Technology in South Africa*[198] was produced by ASSAf in 2017 and was subsequently endorsed by Cabinet. The 2017 report provides a detailed profile of the research actors and funders on climate change, particularly those that are relevant to national development priorities.

It is noted that the report limits its focus to climate change and not the broader 'global change'. This distinction is important as it was the very basis for the design of the Global Change Grand Challenge identified in the 2008–2018 Ten-Year Innovation Plan. Even though the focus of the report is limited to climate change science, the report provides some valuable insights and establishes a valuable basis from which to undertake the HESTIIL review.

The following observations from the 2017 ASSAf report[199] are significant for this review:

- Of the several hundred international institutions that produced research publications related to climate change and the southern African region, just one to a few outputs were related to South Africa.
- The entire system is underperforming with respect to implementation of climate change adaptation and mitigation actions.
- The poor performance is partly due to the poor coupling between research and the development elements of the South African system. In this regard, the ideas developed are poorly aligned to market and societal needs. It is also possible that there is underfunding of development relative to research.
- With some exceptions there is a tendency for the South African private sector to rather import tested technologies.
- A new data collection body is not proposed, but policy reports such as the ASSAf report, institutional reporting and DST R&D survey instruments must be strengthened.
- There is an urgent need to address the obstacles and high costs of accessing data generated through public funded programmes.
- Climate-change-related R&D investments need to be sustained and directed over decadal planning horizons, not on a yearly basis.
- In principle, funding derived from national sources is aligned to national priorities, such as those articulated in the NDP and the Medium-Term Strategic Framework (MTSF) although there is no rigorous process to ensure this.

What stands out in the report is the finding that the whole system is underperforming, and this is partly due to poor coupling between R&D and the realities of market and societal needs. Important also is the observation that this area requires increased funding, and the research timeframes need to be extended beyond one year. This should not come as a surprise. In this regard it is noteworthy that the bulk of the Global Change DSI funding is directed through the NRF Research Chairs and Centres of Excellence on Climate Change or Earth Sciences. There is also special funding for programme facilities at the NRF, such as SAEON and SARVA.

[197] Department of Environment Affairs, 2012. *Environment Sector Research, Development and Evidence Framework: An Approach to enhance science-policy interface and evidence-based policy making*. Department of Environment Affairs, Pretoria. Available website https://www.dea.gov.za/documents
[198] Ibid.
[199] Ibid.

The implication is that the research community competes for short-term funding for activities that are aligned with the 'Science Plan' on Global Change. This does not guarantee that all areas of the science plan will be addressed as it is totally dependent on responses from the research community. This scenario is completely different to one where an institution is mandated to implement the 'Science Plan' and then reports to the Minister, DSI and Parliament on any areas of the science plan that are neglected. The research grant funding support that the NRF provides for building globally prominent research capacity is critical and must continue. However, as the 2017 ASSAf Climate Change Science report also notes, there is an urgent need to invest in much more applied R&D. This should not cause for funding to be directed away from the critical hubs of research excellence that exist within the university research chairs programme. Rather, it should provide a vehicle for pulling together the interdisciplinary research teams to address the development challenges facing society, the economy and the environment.

Apart from the university sector, there are research institutions that include the Agricultural Research Council (ARC), the South African Biodiversity Research Institute (SANBI), the Water Research Commission (WRC) and the Council for Geosciences (CGS). In contrast to the growth in environmental research funding to universities, these research institutions have had to reprioritise within their research budgets to demonstrate engagement with the Global Change Science Plan. In other words, this has not always translated into growth of the 'research enterprise' in the very institutions that are at the coalface of the more applied research battlefield. It is critical to note that these are sector-based research institutions and the national development challenges in this area are intensely complex and require multi-disciplinary research efforts. If there isn't an earth science research institution, then one would expect to find these sector research institutions forming cluster programmes (e.g. including ARC, WRC and SANBI) to take up responsibility for implementing applied research activity in one or more aspects of the Global Change science plan across one of the more vulnerable regions of the country.

There had been some understanding that this is what the CSIR-based Applied Centre for Climate and Earth System Sciences (ACCESS) was established to do, but there is no evidence that ACCESS has been adequately institutionalised to provide such a national drive and focus. It is instructive to dwell a little bit more on the early coordination efforts in Earth Systems research.

4.3.4.5 Early developments in coordinating South Africa's earth-system scientific research

Amongst the earliest efforts to pull together trans- and multi-disciplinary science and technology activities across the South African national system of innovation was the establishment in 2008 of the CSIR-led programme, the Applied Centre for Climate and Earth System Sciences (ACCESS). Figure 4.21 provides a profile of the many actors in the earth systems arena and indicates the various participants that were involved in the ACCESS programme. A review of the programme in 2014 affirmed the excellent research activities that were supported by ACCESS and, in the context of strengthening the programme, raised questions on the sustainability of the organisational form and the scale of operations[200].

Even earlier than ACCESS, the South African Environmental Observation Network[201] (SAEON) was established at the NRF with ringfenced funding support from the DST. Today SAEON's spread of activities has grown to include support for research activities performed by members of the observatory nodes who are also usually members of ACCESS. Following the review of ACCESS and

[200] Review of the DST-NRF Applied Centre for Climate and Earth System Sciences (ACCESS) – 2014. Available DST website https://www.dst.gov.za

[201] NRF – South African Environmental Observation Network (SAEON). Available NRF website https://www.nrf.ac.za

developments on the international front, the DST and the NRF were encouraged to work on establishing an 'Earth Systems Science Research Programme[202] (ESSRP), which was established only in 2018. The international developments include the establishment of the 'Future Earth' initiative, described as an amalgamation of the previously distinct programmes of the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programmes (IHDP) and the International Programme on Human Diversity (Diversitas) where the World Meteorological Organisation is an observer.

The NRF - ESSRP has prioritised the following research thrust areas:

NRF: EARTH SYSTEM SCIENCE RESEARCH PROGRAMME (ESSRP) 2018

- Sources and consequences of climate change and variability at all time scales;
- Building a predictive understanding of societally relevant linkages and feedbacks between land, ocean, atmosphere and climate [fostering links with the Marine and Antarctic research programmes where appropriate];
- Direct effects of rising CO_2 and other anthropogenic pollutants on marine and terrestrial ecosystems and biodiversity, and biophysical processes;
- Quantifying trends in and developing a predictive understanding of ocean and terrestrial greenhouse gas fluxes, causes and sinks [fostering links with SAEON and the Expanded Freshwater and Terrestrial Environmental Observation Network (EFTEON) infrastructure where appropriate and feasible];
- Environmental risks of geo-engineering solutions for carbon sequestration or planetary albedo management;
- Trends in and consequences of ecosystem transformation and utilisation for terrestrial and marine ecosystems, including biodiversity;
- Hydrological and other relevant consequences of land cover change, ecosystem transformation and utilisation and climatic change in terrestrial ecosystems;
- Impacts of climate change mitigation and adaptation programmes on southern African ecosystems and societies, including the impact of adaptation options such as water management, intensification of agriculture, etc.; and
- Relationships between biodiversity and ecosystem resilience and relevant links to human society.

While the 2018 ESSRP does provide a single portal through which research funding is channelled for climate-related and earth systems science, it still falls short of addressing the issue raised in the 2017 ASSAf report. In this report stakeholders raised the concern that there is considerable work on what the climate change challenges are but very little, if any, applied work on developing solutions**.** While this matter does fall outside the mandate of the NRF, this is a crucial mandate difference between the NRF grant-funding institution and research-performing institutions that requires remediation.

There are a few scenarios on how to structure the coordination function to generate the science-based decision-support required by government and the 'applied research' that will go beyond published science to explore technological and engineering solutions. Before outlining some possible options, it may be useful to provide a few snapshots of the current research activity in the earth system sciences area. The list below provides an indication of the involvement of the higher education sector in South Africa in earth sciences/climate change sciences with a number of Research Chairs awarded by the DSI/NRF programme to various universities. Some of these Research Chairs were set up in direct response to the 10 Year Innovation Plan Grand Challenge on Global Change.

[202] NRF - *Earth System Sciences Research Programme (ESSRP), Framework Document and Funding Guide* – July 2018. Available NRF website https://www.nrf.ac.za

SOUTH AFRICAN RESEARCH CHAIRS (DSI/NRF)

- Earth System Sciences **(Nelson Mandela University);**
- Global Change Social Learning Systems Development: Transformative Learning and Green Skills Learning Pathways **(Rhodes University);**
- Interdisciplinary Science in Land and Natural Resource Use for Sustainable Livelihoods **(Rhodes University);**
- Social-Ecological Systems and Resilience **(Stellenbosch University);**
- Sociology of Land Environmental and Sustainable Development **(Stellenbosch University);**
- Climate Change **(University of Cape Town);**
- Ocean Atmosphere Modelling **(University of Cape Town);**
- Environmental and Social Dimensions of the Bio-Economy **(University of Cape Town);**
- Social Change **(University of Johannesburg);**
- Ecosystem Health and Biodiversity in KZN and the Escapee **(University of KwaZulu-Natal);**
- Land Use Planning and Management **(University of KwaZulu-Natal);**
- Ecosystem Health: Monitoring and Managing the Health Resilience of the Limpopo River Basin **(University of Limpopo);**
- Biodiversity Value and Change in the Vhembe Biosphere Reserve **(University of Venda);**
- Exploration, Earthquake and Mining Seismology **(University of Witwatersrand); and**
- Global Change and Systems Analysis **(University of the Witwatersrand**).

Figure 4.21 below maps out some of the major players in Earth Systems Science.

CURRENT SOUTH AFRICAN NSI EARTH SYSTEM SCIENCE (INDICATIVE)

Applied Centre for Climate and Earth System Science (ACCESS)
COMMENCED 2008....
REVIEWED 2013 /14
- Council for Scientific and Industrial Research (CSIR)
- South African Weather Service (SAWS)
- Council for Geological Survey (CGS)
- Agricultural Research Council (ARC)
- South African Biodiversity Institute (SANBI)
- Medical Research Council (MRC)
- National Research Foundation (NRF)
- South African Institute for Aquatic Biodiversity (SAIAB)
- South African Environmental Observation Network (SAEON)
- Walter Sisulu University
- University of the Witwatersrand
- University of the Western Cape
- University of Venda
- Stellenbosch University
- Rhodes University
- University of Pretoria
- University of Limpopo
- University of Fort Hare
- University of Cape Town
- University of Kwa Zulu-Natal
- South African Association for Marine Biology
- ORI

Ten-Year Innovation Plan Grand Challenge: GLOBAL CHANGE
IMPLEMENTATION COMMENCED 2008 to 2018

DST/NRF Research Chairs and Research Centres of Excellence Programmes
INITIATED 2008

SOUTH AFRICAN RISK AND VULNERABILITY ATLAS (CSIR-led programme)
First Edition 2012 and second Edition 2018 as a Global Change eBook
Electronic spatial database and information system curated by SAEON

South African Environmental Observation Network (SAEON) NODES
- Arid Lands (western half of South Africa
- Egagasini (marine off-shore)
- Elwandle Coastal (Port Elizabeth)
- Fynbos (Western Cape)
- Grasslands, Forests and Wetlands
- Ndlovu (Kruger Park/savanna biome)

National Research Foundation: Earth System Science Research Programme (ESSRP)
COMMENCED 2016

Southern African Science Service Centre for Climate and Land Management (SASSCAL)
Southern African government consortium plus government of Germany represented by BMBF
Angola; Botswana; Namibia; South Africa; Zambia.
Key issues: Food security; Water security; Biodiversity conservation; Sustainable forests and woodlands; Environmental data and information for decision-making; Climate-change risks and vulnerability.

Department of Environmental Affairs 2012 Environment Sector RD&E Framework priorities
- Biodiversity - Waste Management - Climate Change - Air Quality - Oceans and Coasts

Figure 4.21: Some R&D performers in earth systems sciences

4.3.5 RDI for a sustainable energy mix

4.3.5.1 The socio-economic context

The National Development Plan: Vision 2030 was adopted in 2012 and recognised that access to electricity is a core element of a decent standard of living. Eight years later and the country has, as recently as November 2019, been subjected to Stage 6 load shedding with the national grid forced to reduce baseload supply from the grid by approximately 6000 MW at extremely short notice. The impacts have been felt across society and industry with constant power blackouts. The CSIR Energy Research Centre is to be commended on the work that assisted in informing the new direction for energy supply as is evident in the position announced by the President in his 2020 State of the Nation Address. The CSIR study questioned the seriousness of the energy crisis facing South Africa and the spectrum of possible responses over the short, medium and long term[203]. The study reported that the estimated cost to the economy of the 2019 load shedding was approximately R60 Billion to R120 Billion. This was estimated using COUE (cost of unserved energy at approx. 87.50 R/kWh).

The proposed responses announced by the President include:

- A national customer response drive to 'power-up' with relaxation of bureaucratic impediments to extending the contracting scope with existing Independent Power Producers (IPPs);
- New IPP bid windows using renewable energy supply technologies;
- Municipalities enabled to purchase more energy supplies from IPPs;
- Industry and private operations enabled to generate more of their supply requirements;
- Dramatically relaxed regulations to allow for more self-generation operations to take pressure off the grid; and
- Encouragement in the very immediate term of small-scale embedded generation (SSEG) for residential, embedded generation (EG) for commercial or agricultural requirements and embedded generation (EG) coupled with distributed generation (DG), provided the systems are aligned with the technologies defined in the 2019 Energy Mix Integrated Resource Plan (IRP).

The Integrated Resource Plan (IRP) 2019 says that *'Energy security in the context of this IRP is defined as South Africa developing adequate generation capacity to meet its demand for electricity, under both the current low-growth economic environment and even when the economy turns and improves to the level of 4% growth per annum. Generation capacity must accordingly be paced to restore the necessary reserve margin and to be ahead of the economic growth curve at least possible cost'.*

South Africa's ambitions for energy security go beyond meeting power-generation capacity. The same IRP notes that the energy sector contributes close to 80% towards total greenhouse gas (GHG) emissions, of which 50% is from electricity generation and liquid fuel production. Further, globally, energy-storage technologies remain a great challenge. In the policy studies undertaken in the run-up to the White Paper on the STI, NACI commissioned a 'Situational Analysis' study on Innovation. Among the various challenges identified in the NACI analysis, high energy usage per unit of GDP and high carbon emissions per unit of generated power were flagged as having a serious impact on industrial productivity, economic growth and environmental loading. This perspective resonates with a number of goals of the NDP, namely GHG emission reductions, renewable energy generation, and vehicle emission statistics and waste management. Responses to these challenges require research,

[203] CSIR (J. Wright, Dr; J. Calitz). *Setting up for the 2020s: Addressing South Africa's electricity crisis and getting ready for the next decade*. CSIR presentation, 2020. Available CSIR Communications.

technology development, and innovation and technology transfer. This is particularly the case as the benefits can spill over into local manufacturing as well as lower energy costs, improved human health and the integrity of ecosystems. In alignment with the NDP, the Industrial Policy Action Plan (IPAP) has further included a focus on developing green industries and job creation. The 2019 IRP presents an introductory comment/referral to the NDP in that *The National Development Plan (NDP) envisages that, by 2030, South Africa will have an energy sector that provides a reliable and efficient energy service at competitive rates, that is socially equitable through expanded access to energy at affordable tariffs and that is environmentally sustainable through reduced pollution.*

4.3.5.2 R&D expenditure in energy

It is virtually impossible to make much of the statistics, however Figure 4.22 provides some insight into investment in research and experimental development from the 2017/18 National Survey. These figures indicate that it is only business (the private sector) that is spending significantly on both energy resources and energy supply (generation). There is also some evidence of this in the case of universities and non-profit organisations. The focus of state-owned enterprise research is generally on energy supply (generation).

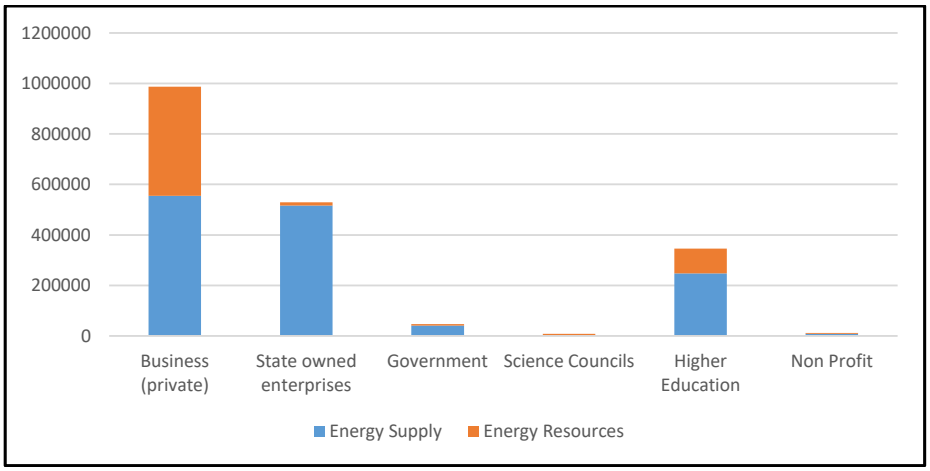


Figure 4.22: Expenditure on energy and energy resources R&D, 2017/18

4.3.5.3 The research base

It was not possible to access the same level of detail on the energy research base as the National R&D Survey does not provide a breakdown at the level of researcher numbers in the field of energy research. This is only reflected under socio-economic objectives. There is some useful information available on the research chairs programme that is designed to support the university research agenda in building the pipeline of future researchers. ASSAf produced a report in August 2014 on the State of Energy Research in South Africa[204], a report commissioned by the South African National Energy Development Institute (SANEDI). The study references the 2013 Department of Energy Integrated Resource Plan (IRP), the 2008 DST Ten Year Innovation Plan, the NDP-Vision 2030 and the National Energy Act of 2008. There will have been considerable development since the 2014 ASSAf study commissioned by SANEDI, however the 2018 list of DSI/NRF Research Chairs reflects the same pattern of distribution across the higher education sector. ASSAf found that holistically (and beyond the Chairs and Centre of Competence programmes), university institutional strengths are found in:

[204] SANEDI.

- Renewable energy at SU, UCT and Wits;
- Energy efficiency at NWU, Wits, UCT, UP and UJ;
- Fossil-based energy at Wits and NWU;
- Nuclear energy research at NWU;
- Storage and hydrogen fuel-cells at VUT, UWC, Wits, UCT, NWU and UJ;
- Energy and the environment at Wits, UCT and UP; and
- Modelling and control at CPUT, UCT and Wits.

The ASSAf report also found that the university sector dominates energy research outputs in publications at 88%, with seven DSI/NRF research chairs, three DSI Centres of Excellence (with strong university-based components), eight Eskom research chairs across the higher education sector and a further seven centres or specialist institutions. Some of these centres or specialist institutions were established by the universities themselves before the Chairs or Centres of Competence programmes were established.

The ASSaf report further notes that in terms of the production of patents in the energy field, the private sector dominates, accounting for 76% of registered patents over the period 2000 – 2014. Sasol generated the most patents, followed by the Pebble-bed Modular Reactor (PBMR). The ASSAf study recommended the following as major priority areas for energy RDI:

- Coal, with methods to ensure the cleaner use of coal in South Africa, is of immediate and paramount importance;
- Gas, with a focus on exploiting potential shale gas deposits;
- Renewable energy inclusive of small-scale, off-grid systems, especially for rural areas;
- Nuclear energy (note the period under review reflected a great deal of confusion on the state's position);
- Energy efficiency and demand-side management (DSM); and
- Energy economy and policy inclusive of techno-economic feasibility studies and development roadmaps.

What is significant when examining the research focus of the university chairs is that a number of them (such as the University of Fort Hare, University of the Western Cape and University of Cape Town) participate in a larger programme with science councils (i.e. Mintek and the CSIR) as well as industry on various aspects related to developing the industry for a 'hydrogen/fuel cell'-based economy. Disappointingly, this work is not yet on the radar of the government's Integrated Resource Plans.

Government's policy position in the 2019 IRP is that coal will play a significant role in baseload capacity as it comprises the largest share of installed generation capacity. Global financing requirements, however, are critically dependent on clean coal technologies such as the high-efficiency, low-emission (HELE) coal technologies. This would include the development of supercritical and ultra-supercritical power plants and carbon capture, utilisation and storage (CCUS) technologies for coal-based energy generation. The 2019 IRP does commit to an increasing proportion of renewable energy capacity and much greater flexibility in both the mix of energy-generation sources and the supply into and off the grid. The 2019 IRP recognises that renewable solar, photo-voltaic (PV) and concentrated solar plants (CSP), and wind energy with storage capability provide an opportunity to further diversify the electricity mix to produce distributed generation and to provide off-grid electricity. The Plan recognises that it is in the renewable energy technology space that considerable potential exists for the creation of new industries and jobs as well as localisation across the value chain. Biomass from waste, paper and pulp, and sugar industries could even be utilised in co-generation plants and deliver electricity at a price-competitive level with minimal transmission and distribution infrastructure

requirements. It is also noted that the nexus between biomass and a government-backed biofuels programme could improve the economics of the initiatives and create opportunities in rural and urban centres.

4.3.5.4 Research direction-setting and coordination

The ASSAf report flagged as 'very important' the finding that, *"…in general, coordination and cooperation in energy and energy-related R&D is insufficient, resulting in overlap/duplication and gaps in terms of national priorities. This is partly due to the fact that the energy and energy-related budgets are located within multiple state departments and state-owned enterprises."*

Figure 4.23 below demonstrates the scope of research taking place in energy as well as the level of fragmentation in this sector**.** Failed efforts to develop an integrated energy research programme are discussed in detail at **Annexure B**.

ENERGY RESEARCH LANDSCAPE

Grant Funding

National Research Foundation (NRF)

- *DSI/NRF SARChi Research Chairs*
- *Bursaries Programme*

Technology Innovation Agency (TIA)

- Renewable Energy (alternative transportation, solar thermal energy, wind energy, PV systems, hydro energy)
- Bio-energy (microalgae to energy, biodiesel, waste to energy)
- Energy safety (energy management)

University of the Western Cape

- DSI/NRF **Chair** of Energy Research: Nano-Electrochemistry and Sensor Technology
- DSI/Hydrogen South Africa **Centre of Competence**: HySA systems for innovation in fuel-cell systems
- Eskom **Chair**: Renewable Energy Technologies
- University **Centre**: South African Institute for Advanced Materials Chemistry

Stellenbosch University

- DSI/NRF **Chair** in Biofuels and Other Clean Alternative Fuels
- DSI/NRF **Chair**: Energy Research
- DSI **Programme** in renewable energy or energy-related research: **Centre** for Renewable and Sustainable Energy Studies

University of Cape Town

- DSI **Centres of Competence**: UCT and Mintek: HySA catalysis for innovation in fuel catalysis
- Eskom **Chair**: Materials Engineering
- Energy Research **Centre** (Energy Policy, Climate Change, Modelling)

North-West University

- DSI/NRF **Chair** in Biofuels and Other Clean Alternatives
- DSI/NRF **Chair** in Nuclear Engineering
- DSI **Centre of Competence** in partnership with CSIR – Hydrogen South Africa infrastructure for Innovation (hydrogen production, infrastructure, codes and standards)
- Eskom **Chair** in Emission Control Technologies
- Unit for Energy Systems

Cape Peninsula University of Technology (CPUT)

- South African Renewable Energy Technology Centre

University of the Witwatersrand

- SANEDI **Chair**: Clean Coal Technologies
- Eskom **Chair**: Combustion Engineering
- Eskom **Chair**: High Voltage Engineering (AC)

University of Pretoria

- Eskom **Chair**: Plant Asset Management
- Energy **Cluster**: Energy **Hub** in Energy Efficiency

Tshwane University of Technology (TUT)

- DSI/NRF **Chair:** Energy Production and Consumption for Sustainable Global Survival

Nelson Mandela University Centre for Renewable Energy Research: Photo-Voltaics yield testing and training facility (partners with equipment manufacturers)

University of KwaZulu-Natal

Eskom **Chair:** High Voltage Engineering (DC)

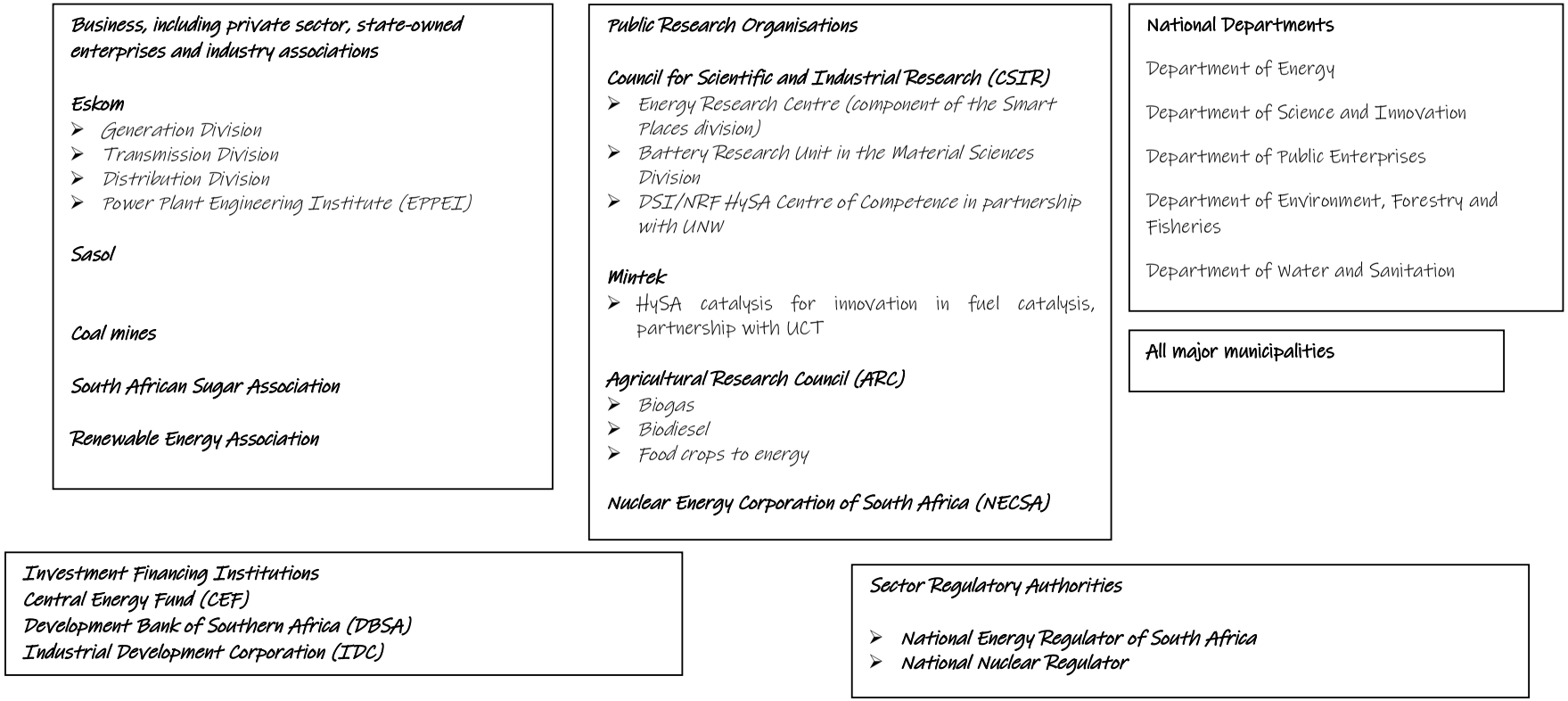


Figure 4.23: Energy research landscape[205]

[205] Source: ASSAf State of Energy Research 2014 report, NRF 2018 list of research chairs and other literature.

4.3.6 Nutrition and food security

4.3.6.1 Socio-economic context

The COVID-19 pandemic has exposed the harsh reality of the depth, severity and devastating consequences of South Africa's inequality. The country ranks among the world's three most unequal societies when measured against any set of metrics. The NDP Vision 2030 set a target of lowering the country's Gini coefficient from 0.69 to 0.6 by 2030. All indications are that this target will not be achieved. This is in stark contrast to the reality that South Africa is self-sufficient in most agricultural products except wheat, poultry and red meat. In recognising that part of the problem lies in the structure of the economy, food production and food markets, the NDP also targeted the achievement of a food trade surplus, with one third produced by small-scale farmers or households.

Food security involves a complex set of economic activities requiring research and production efforts across multiple disciplines, with constant attention given to human, animal and plant health, and water and earth resources. Evidence of this vigilance is found in the 'track and trace' requirements for food products that are in force around much of the developed economies. South Africa, with significant agricultural exports, is also subject to compliance at quite a cost. In addition to the 'track and trace' requirements, the country incurs high costs to maintain and to have accredited certification of production practices. The country is also vulnerable to a range of pests such as the fall armyworm and animal diseases such as swine fever as well as foot-and-mouth disease. In addition, further downstream, in food processing there are added health risks as became evident with the recent outbreak of listeriosis linked to processed meat. An important dynamic in food security is the link to nutrition and health. Even developed countries are grappling with challenges of nutrition despite having achieved food security and food sovereignty. Just by way of example, a 2016/17 policy research study supported by the Human Rights Commission found that 25% of South African toddlers (1–3 years old) are nutritionally stunted and that this nutritional stunting is costing the country about R40 billion annually[206].

4.3.6.2 R&D expenditure in food security

The food security/food sovereignty construct involves more than the agricultural sciences. Fields of study include the environmental sciences, social/economic, social sciences and the humanities (e.g., legal ramifications) as well as business management disciplines. Unfortunately, data on investments in research across the entire spectrum of research fields in this area is not readily available. What is available is the National R&D Survey results for expenditure in the field of agricultural sciences across the different sectors is illustrated in Figure 4.24. It is in agriculture and in environment-related science fields that the business sector spends far less than the science councils. What is also of concern is the seemingly low investment by the higher education sector.

[206] Ramkissoon Y. South African Human Rights Commission: Policy Research Brief: *The Right to Access to Nutritious Food in South Africa 2016-2017.* Available sahrc.org.za/Section 184(3) Reports.

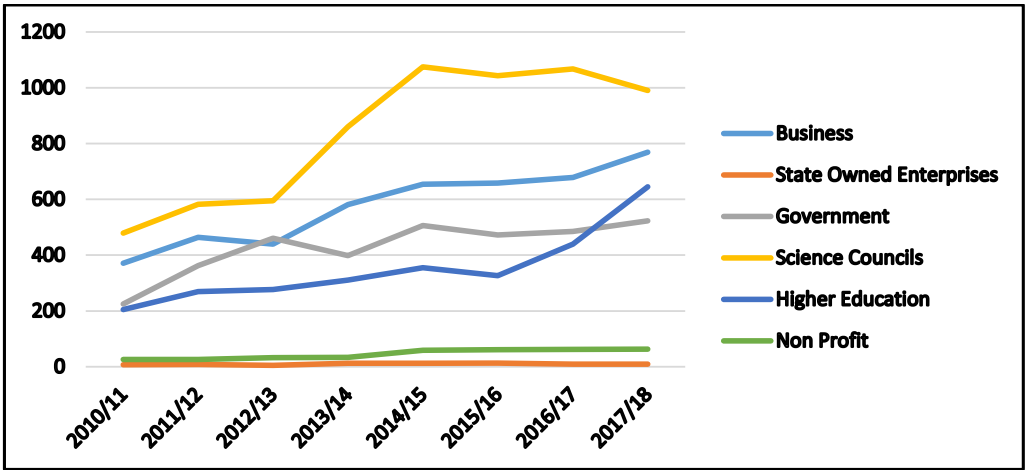


Figure 4.24: R&D expenditure in agriculture 2010/11 to 2017/18 in R'millions[207]

4.3.6.3 The research base

As mentioned previously, the challenges related to food security and sovereignty cover a wide range of research fields and statistical data in these areas is not readily available. The National R&D Survey also does not provide data on full-time equivalent (FTE) or headcounts of researchers in agricultural research. The CREST-SciSTEP report on the state of the research enterprise does however provide a comprehensive profile of the agricultural sciences and notes that the number of FTE researchers has largely remained unchanged for the past two decades[208]. The report notes that by 2014, this number had stabilised at around 800. The CREST/SciSTEP study notes the deficit in terms of the number of institutions and mechanisms to support impact assessment studies of interventions to reduce hunger, malnutrition and poverty. The CREST/SciSTEP report also flags another important matter: the areas of specialisation between master's and doctoral graduates, point to distinctly different career expectations at these exit points. The fact that increases in the pipeline are occurring at a time when the FTE research base is not expanding, suggests that large proportions of graduates are going into areas that are only marginally related to scientific research in agriculture. This may explain the observation made during our stakeholder engagements with the ARC that the institution has made excellent progress in improving the numbers of its own staff with PhD and master's qualifications. The ARC has faced serious challenges over the years in attracting and rejuvenating its base of researchers.

The number of organisations in the Food Security and Sovereignty and Agriculture domains are too many to list. The list includes science councils, other government agencies, university-based research chairs and centres of excellence, industry, state-owned enterprises and non-profit organisations. With a focus primarily on the research effort, this study draws on those entities that are productive in research outputs such as publications; cognisant of the fact that there are instances where the research output is intellectual property or breeders' rights which can be licensed to other commercial businesses.

4.3.6.4 Researchers

The CREST/SciSTEP 2019[209] report on the state of the research enterprise established that the growth rate of instructional staff at South African universities increased marginally by 1.3% in the period

[207] Sourced from ASTI-CGIAR 2018 data by CREST/SciSTEP.
[208]Sourced from ASTI-CGIAR 2018 data by CREST/SciSTEP.
[209] Sourced from ASTI-CGIAR 2018 data by CREST/SciSTEP.

2000–2015. The report also notes that over the same period the increase in instructional staff in the field of agricultural sciences reached an impressive rate of 3.4%, as illustrated in Figure 4.25.

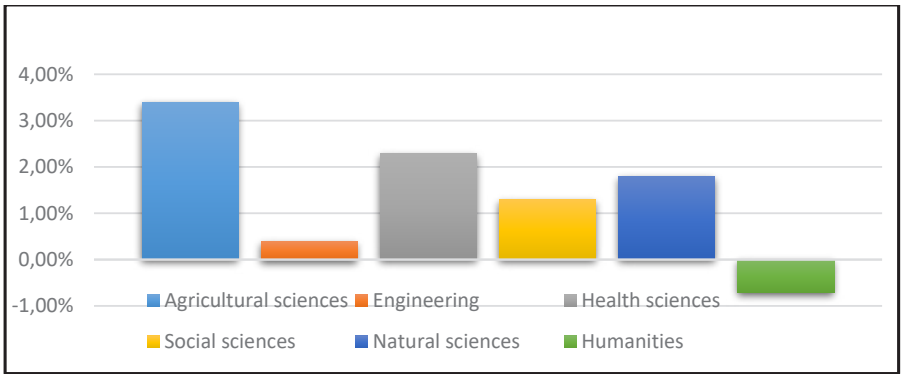
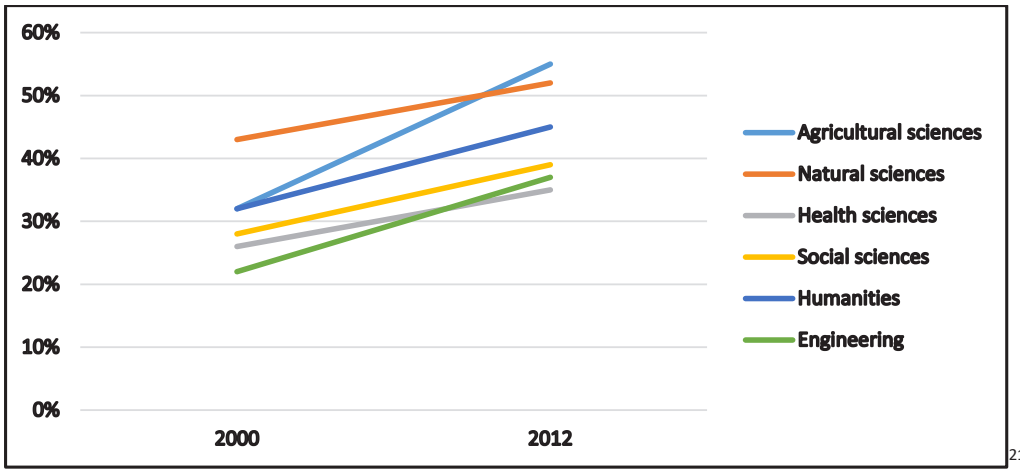


Figure 4.25: Growth rate of permanent instructional staff and universities, 2000–2015[210]

As noted in the report, what is more important is to examine the rate of growth of staff with PhDs in each field. The value of this indicator points to increased capacity to teach, undertake research, innovation and technology transfer and supervise the next generation of scientists with master's qualifications and PhDs. Again, as indicated in Figure 4.26, there has been strong growth in the field of agricultural sciences over the period 2000 to 2015, from 32% of university staff with PhDs in 2000 to 55% of university staff with PhDs in 2015.



[211]

Figure 4.26: Proportion of university staff with PhD qualifications[212]

The most recent NRF update on the researchers in the agricultural sciences across the institutional landscape is available at **Annexure B**.

4.3.6.5 Research direction-setting and governance

[210] Ibid
[211] Ibid
[212] Crest ScieSteo 29

The national Department of Agriculture has the oversight mandate in setting the research agenda for the country, supported by its agency the Agricultural Research Council. The agricultural research domain is one of the few areas that enjoy strong support from the stakeholder department, as is evident in the growth in the financing of R&D.

4.3.7 RDI for industrial diversification, growth and future jobs

South Africa's Industrial Policy Action Plan (IPAP) Ten-year Legacy Report[213] refers to several policy interventions in the *containment of de-industrialisation.* The Report also recognises serious challenges facing the economy *in the face of accumulating seismic changes in technology and shifts in the structure and systems of global production*. These are crucial observations that we consider in this Review with respect to the impact of advanced digital production (ADP) and the direction in which the more competitive economies are moving. These developments are occurring while growth in the South African manufacturing sector's share of gross domestic output is rapidly shrinking.

The remediation task for the nation is a daunting one. The DTI IPAP Legacy Report provides a narrative on the industrial scale response required to the range of 'structural fault-lines' that are noted in the National Development Plan[214] such as skewed racial demographics, gender bias and geographic polarisation across provinces. The challenges are further compounded by a fraught reality that presents itself across other developing economies: the persistent and growing challenge of converting R&D results into commercial and social realities.

Particularly noteworthy in the IPAP Legacy Report is the observation that these advanced production technologies and systems *are already posing massive challenges to our national systems of skills, science and technology*. There is a cooperative engagement between the DTIC and the DSI with respect to the leadership of the DSI investments in the research, development and innovation (RDI) platforms required to establish new foundations for what is described globally as 're-industrialisation' for the Digital Age. Beyond this there is no structured route to manufacturing and commercialisation.

The government's response to this gap is the establishment of the 'Sovereign Fund', which is expected to support increased deployment of science and technology infrastructure as well as commercialisation of R&D in the new digital technologies economy. The question is whether vital lessons learnt from the DSI Sector Innovation Fund and the DTIC incentives – of such support mainly benefiting existing industry development at the 'low-value-add' spectrum of production technologies – will be analysed and remediated.

A strong concern is that industry is so far from adoption of these new technologies that it may be necessary to strengthen the mandates of existing state-owned enterprises and public research organisations to spin out bold new commercial operations. This can be achieved by state-led exploitation of home-grown breakthroughs in photonics, nanotechnology, biotechnology and relevant technology transfer and diffusion.

4.3.7.1 Socio-economic background

South Africa's industrial policy and strategy are significantly focused on the strategic diversification of a mix of economic activities. They are also focused on the promotion of job creation for a sustainable growth path. With unemployment stubbornly above 25% and heading to beyond 30% (among the highest in the world), the mood in the country is desperate, particularly as external shocks such as

[213] The dti, 2018. *Industrial Policy Action Plan 2018/19 – 2020/21*. Department of Trade and Industry. Pretoria.
[214] Ibid.

deepening and widening trade wars coupled with communicable diseases such as COVID-19 are having a devastating impact that is felt deep in South African export and import supply chains.

The National Development Plan: Vision 2030 addresses South Africans in terms of **Our future – make it happen**. This assumes that there is considerable confidence that the objectives of the Plan are realistic and achievable. To some extent these objectives still looked realistic in 2017. Considering the trade surplus figure of 2017, amounting to R79.9 billion, there could have been little doubt that the aspirations of the NDP Vision 2030 could be achieved. According to the South African Revenue Services (SARS), however, high commodity prices, the depressed oil prices and lower oil consumption at the time accounted for much of the positive trade outcome. Nonetheless, it is still significant to note that the records show that the economy had the capacity to produce and export R1.1 trillion and R1.3 trillion in goods to the rest of the world in 2017 and 2019 respectively[215].

South African imports are extremely high, so much so that it is mainly currency fluctuations and externalities such as the oil price movements that allow for a surge into a trade surplus. According to the SARS 2017 report on exports and imports, the country has demonstrated that it can perform well in exports, so much so that it cannot be definitively said that it is a net exporter or a net importer. This is why future possibilities are so promising. The localisation drive to push up use of local manufactured goods and services rather than imports is not too dissimilar to that followed by the United States and other countries. The key is that South Africa can ramp up local production to reduce its level of imports. The government has for some time sought to use strong levers, notably the state *spending muscle* to do just that. The National Treasury Budget Infrastructure Update 2020 on estimates of national expenditure includes an annexure that provides an update on projected infrastructure spending[216] in the public sector. The Infrastructure Update 2020 notes that *'… in line with government priorities and the medium-term strategic framework, the 2020 budget prioritises spending on social and economic infrastructure such as schools, health facilities, roads and transport, energy, water and sanitation'*. The report notes further that R3.2 trillion was spent on infrastructure by the public sector over the period 1998/99 to 2018/19. This was, roughly speaking, the same target that had mobilised the government to use its *spending muscle* to drive economic transformation interventions such as Broad-Based Black Economic Empowerment (BBBEE) quota requirements in state procurement, and more recently 'local manufacturing' percentage targets within this same state procurement system.

In addition to that of the deep-rooted culture of corruption that impeded service delivery within SOEs and other state organs, there are other significant challenges. For example, a key concern raised in the National Treasury's Infrastructure Update 2020 is insufficient capacity and skills to build a sustainable pipeline of projects. This gap is even more significant now that a National Infrastructure Fund, resourced at R100 billion, is being established in a partnership between government and the private sector. The evidence for this capacity and skills gap is seen in rising infrastructure backlogs and a lack of business confidence. The National Treasury is taking steps to address these challenges.

4.3.7.2 Investment in R&D in manufacturing

The DTI's IPAP 2017/18 Legacy Report recognises the importance of investment in R&D in manufacturing. For example, the commercial agricultural sector, which falls squarely in the economic 'Primary Sector', is now highly mechanised and dependent on satellite-sourced information, sensors and other process technologies and IT tracking software. The sector is also increasingly impacted by the 'environmental' constraints relating to production methods and product packaging. Where, in the past, investment was driven in the context of land, labour, capital and entrepreneurship, competitive

[215] SARS Trade Statistics. Available www.sars/trade statistics/tools.
[216] National Treasury (February 2020). Available www.national treasury.gov.za/Budget 2020/infrastructure update.

advantage is now driven by access to advanced knowledge, high-end human capital and technologies. It is also argued that agricultural crops can now be grown anywhere in the world and no longer only in the areas of the natural habitat.

This situation holds equally true for other economic sectors. Thus, the pathway to the re-industrialisation of the economy requires laying new knowledge foundations across the manufacturing base in, for example, micro- and nano-electronics, photonics, industrial biotechnology and advanced manufacturing by means of advanced materials, advanced process technologies and green technologies. These knowledge- and innovation-centric capabilities are the main focus of the European Union strategy on 'Factories of the Future' and are also found in the South African Advanced Manufacturing Technology Strategy (AMTS), the National R&D Strategy of 2002, the 2008 Ten Year Innovation Plan as well as the 2020 NACI Foresight Study Report.

Over the past twenty years, government has directed research funding support to financing laboratories and other high-cost infrastructures in these areas, however the photonics, nanotechnology and biotechnology industries are still described as 'nascent'. Strikingly, the South African manufacturing base is not developing in these areas and manufacturing's share of economic output measured in GDP terms is shrinking compared to the services sector. Juxtaposed to this is the fact that South Africa can still draw satisfaction from having a manufacturing sector that provides the lion's share of the total amount spent on research in manufacturing. This can be seen in Figure 4.27 that provides the results of the 2017/18 National R&D Survey on research and experimental development.

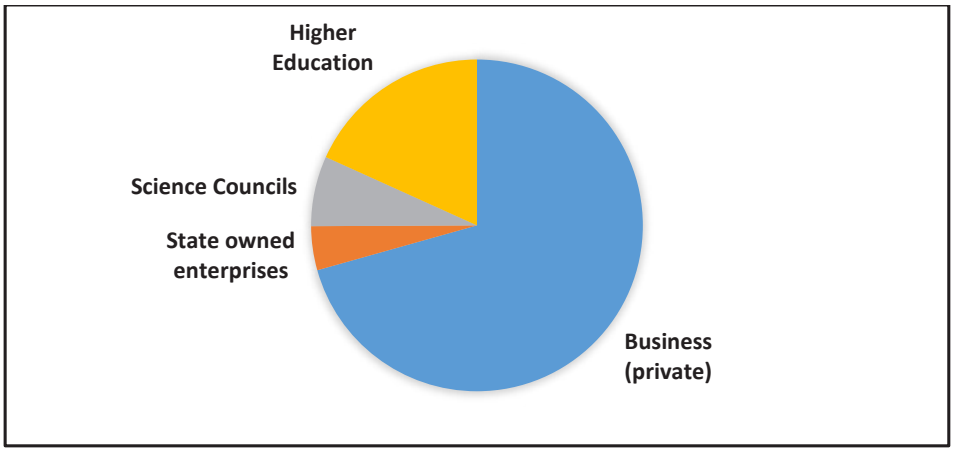


Figure 4.27: Expenditure on R&D in manufacturing by sectors[217]

The pie chart provides an indicative profile of the array of development-support instruments and institutions that are available to industry and researchers in South Africa.

A core responsibility of the DTIC is that of deploying regulatory systems and support for the development of the technical infrastructure that allows for a culture of safe, efficient and high-quality manufacturing processes. For this purpose, the DTIC has oversight of the National Regulator for Compulsory Specifications (NRCS), the South African National Accreditation System (SANAS), the South African Bureau of Standards (SABS) and the National Metrology Institute of South Africa (NMISA).

[217] National R&D Survey 2017/18.

The DTIC development-support instruments are also driving:

- Economic transformation (shifting the skewed demographics of apartheid) through the Black Industrialist Programme;
- Supporting modernisation of the economy through the Manufacturing Competitive Enhancement Programme (MCEP);
- Addressing capacity challenges through the triple helix Technology for Human Resources in Industry Programme (THRIP);
- Supporting innovation in existing industries through the Support Programme for Industrial Innovation (SPII); and
- Supporting innovation for small business growth through the Small Enterprises Development Agency (SEDA).

A dti 2018/19 report on industrial incentives profiles the transformative grant financing in terms of growing new 'black industrialists'. A strong transformative dynamic is built into the incentive that goes beyond racial empowerment and sets up these emerging industrialists for global competitiveness. This is done through steering their investments towards green technologies with a focus on promoting high-value-add manufacturing. The industrial support instrument negotiates an investment multiplier of at least 3 in reviewing grant leverage conditions so that the current R1.5 billion (reflected in Table 4.8 below) as grant funding leveraged a total investment of R5 billion.

Black Industrialists Scheme		
Subsector	**Grant approvals**	**Approval amounts**
Aerospace, rail and automotive components	**4**	**R 88 416 478**
Agro-processing	**7**	**R 240 609 095**
Chemicals, pharmaceuticals and plastics	**18**	**R 454 321 916**
Clean technology and energy	**1**	**R 26 205 000**
Clothing, textiles/leather and footwear	**2**	**R 63 066 000**
Designated sectors for localisation	**1**	**R 50 000 000**
Industrial Infrastructure	**7**	**R 224 325 783**
Manufacturing-related logistics	**9**	**R 289 452 687**
Mineral beneficiation	**1**	**R 19 600 000**
Oil and gas	**2**	**R 88 583 250**
Pulp, paper and furniture	**1**	**R 20 200 000**
TOTAL	**50**	**R 1 564 770 210**

Table 4.8: DTIC Black Industrialists Scheme

In addition to these important efforts, the DTIC has been instrumental in supporting the development of geographically concentrated industrial supply-chain sites. These sites are premised on the 'industrial cluster' approach that catalyses robust production-related interactions (or learning networks) and are typically Special Economic Zones (SEZs) and Industrial Development Zones (IDZs) or Industrial Parks. While industry growth in advanced technology areas is encouraged, the support is provided to existing manufacturers and weighted in favour of a high degree of own capital investment.

The DTIC has taken significant measures to catalyse economic development and there are isolated cases of strong performance by South African manufacturers. However, the uptake of these support measures is typically in high-cost, low-risk developments and most innovation investments are generally described as incremental. The result is that the South African industry has shown a very

weak performance in venturing into the use and development of advanced manufacturing production technology.

The National Advisory Council on Innovation (NACI) completed a review of the design and implementation of the Sector Innovation Funds (SIF) that covers the period from inception in 2013 to 2015[218]. The NACI Report highlights that the SIF programme was made possible with a small slice of the National Treasury budget allocation of R500 million for the period 2012/13 to 2014/15. It is important to get the full context of this allocation.

- National Treasury provided a support package of R25 billion in 2011 for a six-year period.
- The DTIC Manufacturing Competitive Enhancement Programme (MCEP) received R5.8 billion, of which R2.3 billion was allocated to the DTIC Special Economic Zone (SEZ) programme.
- The DSI only received R500 million for the Industry Innovation Partnership (IIP) programme, of which the SIF programme received R135 million.
- The balance of the R500 million funding was deployed for major high-tech RDI projects in photonics (to the CSIR), titanium process technologies (to the CSIR), space technologies (to SANSA), nano-tech upscaling (with the CSIR–Nanotechnology Innovation Centre), and ICT-Industry partnerships (with CSIR–Meraka).

As noted earlier, the focus of the NACI study was on SIF. Among the findings was that the SIF programme contributed to industry renewal in circumstances where traditional sectors that were losing their competitive edge were enabled to diversify into new growth areas. On the downside however, the NACI report found that the triple helix model had similarities with the DTIC's THRIP programme and the DST's TIA programme. In addition, the portfolio of funded sectors lay mainly in the primary or resource-based economic sectors and the selection criteria and process resulted in industrial sectors being chosen that were traditionally well-organised at the sector level but comprised of low-technology, supplier-dominated and scale-intensive industrial operations.

It can be argued that the DSI is already investing the bulk of its budget in the high-technology domains of photonics, smart materials and space-based technologies. However, this is undertaken along a path that never meets the objective of the SIF programme that was designed to support traditional industry sectors to up their game to use RDI to become competitive at the global level. This can only occur if these traditional economic sectors radically modernise their production and process technologies. It is in this gap where the DSI has the responsibility of setting the high-tech bar as high as it should. The NACI report also flagged that, worryingly, the demographics in terms of access to these funds are also still negatively skewed in terms of race and gender. As much as 'head-hunting' is a technique used for finding high-end human resources, this same technique of 'working the networks' can be used to find female- and black-owned businesses in order to secure the larger share of state funding.

4.3.7.3 The research base in manufacturing

It has not been possible in the limited time available to develop and provide the same treatment to the profiling of the research base as was done in the instances of the other RDI clusters. This is simply because the source for detailed statistical information on the researchers and infrastructure is not readily available. What information is available, speaks in general to the industrial base and the research chairs at universities. The manufacturing base is still broadly concentrated within six industry sub-sectors, i.e., food processing, coke and petroleum products, other chemicals, basic iron and steel, metal products and automobiles. Over 60% of South Africa's exports for 2019 fell into four industry

[218] National Advisory Council on Innovation. 2019. *The Design and Implementation Evaluation of the Sector Innovation Programme*. NACI. Pretoria.

sectors: (i) minerals products (the largest share); (ii) precious metals; (iii) vehicles, aircraft and vessels (primarily assembly, with most of the R&D and design done abroad); and (iv) iron and steel.

Figure 4.28 is an extract from the most recent UNIDO Industrial Report[219] that provides a typology of industries by digital and technology intensity. South Africa's set of 'most productive' economic sectors falls mainly into the low and medium-to-low quadrants in both digital intensity and technology intensity. Only industrial performance in transport equipment, chemicals and pharmaceuticals pulls the economy into the medium-high and high-tech/digital areas.

Typology of South African industries by digital intensity and technology intensity			
		Digital intensity	
		Low and medium-low	**Medium-high and high**
Technology intensity	**Low and medium-low**	- **Food products, beverages and tobacco (ISIC 10t12)** - **Textiles, wearing apparel and leather (ISIC 13t15)** - **Coke and refined petroleum products (ISIC 19)** - **Rubber and plastic products (ISIC 22t23)** - **Basic metals and fabricated metal products (ISIC 24t25)**	- **Wood and paper products, and printing (ISIC 16t18)** - **Other manufacturing (including furniture) and repairs of computers (ISIC 31t33)**
	Medium high and high	- **Chemicals and pharmaceutical products (ISIC 20t21)**	- **Computers, electronics and machinery (ISIC 26t28)** - **Transport equipment (ISIC 29t30)**

Figure 4.28: Typology of South African industries by digital intensity and technology intensity[220]

This situation is again profiled in another graphic presentation by UNIDO identifying South Africa's ranking in respect of countries' level of engagement with advanced digital production (ADP) at the level of 'Follower'. However, the country is categorised as 'User' of the advanced type of production for manufacturing rather than a country that is a producer of ADP technologies[221]. Ten 'frontrunner' countries and 23 'producer' followers operate ahead of this 'User' category that South Africa falls into. Of the BRICS countries, only China is a frontrunner while Brazil, India and Russia are 'producer' followers with South Africa the only BRICS country that is not a producer. Algeria and South Africa are the only countries that do not fall into the categories of 'latecomers' and 'laggards'.

The graphic in Figure 4.29 paints a bleak picture of the capacity of state-owned enterprises (SOEs) and government to draw on science, engineering and technology-based developments to improve service provision and the performance of the utilities[222]. Many of the engineering and research departments of the SOEs, government departments and laboratories have been closed or their operations severely limited. The argument that there has been outsourcing to the universities and science councils does

[219] Ibid.
[220] Source: UNIDO elaboration based on Calvino et al., 2018 and UNIDO 2011.
[221] Ibid.
[222] Source: National Research and Experimental Development Survey 2016/17.

not hold water since there has been counterarguments that the SOEs draw on foreign-sourced science, engineering and technology instead. This matter requires further investigation.

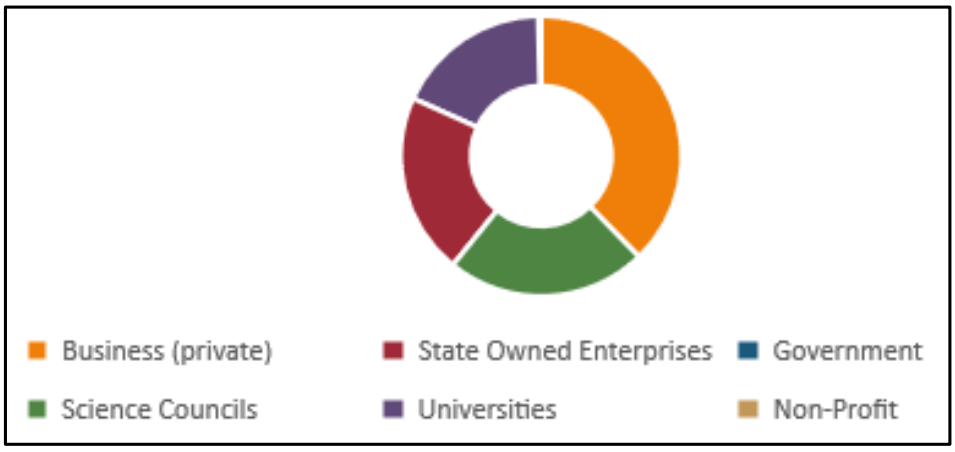


Figure 4.29: R&D in engineering sciences 2017/18

4.3.7.4 STI priorities

The 2020 United Nations Industrial Development Organisation[223] (UNIDO) Report asserts that advanced digital production technology of the Fourth Industrial Revolution (4IR) – i.e., advanced robotics, artificial intelligence, additive manufacturing and data analytics – generates significant opportunities to accelerate innovation and increase the value-add content of production in manufacturing industries. There are concerns that the minimum threshold of skills and capabilities to remain competitive in manufacturing will be so high that it will exclude most countries from this next phase of manufacturing production.

Proceedings from a National Science and Technology Forum[224] (NSTF) Special Meeting in 2016 on light-based technologies (or photonics) highlighted that South Africa has a miniscule impact on the global photonics industry. The factors contributing to this situation included:

- Limited collaboration between universities and industry;
- A lack of automation in manufacturing processing and manufacturing capabilities;
- Domination by imports;
- Low local content;
- A lack of uptake of South African technology; and
- Minimum research, development and innovation (RDI) in the country.

Despite the DSI interventions in lasers, equipment and infrastructure, and triple helix support funding through the Photonics Prototyping Facility (PPF), this profile still holds true for photonics in South Africa. It is also the case across other high-technology domains.

[223] Ibid.
[224] The National Science and Technology Forum provides a platform for industry, business, government and academics to share thinking and reports of progress with regards to STI and stakeholder interests.

Research area	Discipline	Institution
Solid State Luminescent and Advanced Materials	Physical Sciences	University of the Free State
Laser applications in Health	Health and Medical Sciences	University of Johannesburg
Nanotechnology	Chemical Sciences	University of Johannesburg
Industrial Development	Social Sciences	University of Johannesburg
Quantum Information Processing and Communications	Physical Sciences	University of KwaZulu-Natal
Fluorine Process Engineering and Separations Tech.	Chemical Engineering	University of KwaZulu-Natal
Computational modelling of Materials	Technology and Applied Sciences	University of Limpopo
ICT for Development	Information & Communication Sciences	University of South Africa
Advanced Sensor Networks	Engineering Sciences	University of Pretoria
Mathematical models and methods in Bioengineering and Biosciences	Mathematical Sciences	University of Pretoria
Artificial Intelligence	Information and Communication Sciences	University of Pretoria
Carbon Technology and Materials	Engineering Sciences	University of Pretoria
Nano electro chemistry and Sensor Technology	Chemical Sciences	University of the Western Cape
Nanotechnology	Chemical Sciences	University of Zululand
Clean Coal Technology	Chemical Engineering	University of the Witwatersrand
Sustainable Process Engineering	Engineering Sciences	University of the Witwatersrand
Bio-inorganic Chemistry	Chemical Sciences	University of the Witwatersrand
Hydrometallurgy and Sustainable Development	Engineering Sciences	University of the Witwatersrand
Pharmaceutical Biomaterials & Polymer-Engineered Drug Delivery Technologies	Medical Sciences	University of the Witwatersrand
Medical Product Development	Engineering Sciences	Central University of Technology
Micro-Fluidic Biochemical Processing	Chemical Sciences	Nelson Mandela University
Biotechnology Innovation and Engagement	Social Sciences	Rhodes University
Medicinal Chemistry and Nanotechnology	Chemical Sciences	Rhodes University
Functional Nano-structural Materials	Chemical Sciences	Stellenbosch University
Genetic tailoring of Biopolymers	Biosciences	Stellenbosch University
Photonics, Ultrafast and Ultra-intense Laser Sciences	Physical Sciences	Stellenbosch University
Acid-mine-drainage Technology	Chemical Sciences	Tshwane University of Technology
Minerals Beneficiation	Engineering Sciences	University of Cape Town
Drug Discovery	Medical Sciences	University of Cape Town
Biomedical Engineering and Innovation	Health & Medical Sciences	University of Cape Town
Reaction Engineering	Engineering Sciences	University of Cape Town

Bioprocess Engineering	Engineering Sciences	University of Cape Town
Dermatology and Toxicology	Health and Medical Sciences	University of Cape Town
Nano-materials for Catalysis	Chemical Sciences	University of Cape Town
Industrial Computational Fluid Dynamics	Engineering Sciences	University of Cape Town
Scientific Computing	Information and Computer Sciences	University of Cape Town
Computational Mechanics	Mathematical Sciences	University of Cape Town

Table 4.9: South African Research Chairs Initiative (SARChi) aligned to advanced manufacturing funded by the DSI/NRF programme – updated 2020

The UNIDO 2020[225] report shows that only 10 economies account for 90 percent of all global patents and 70 percent of all exports directly associated with the advanced digital production (ADP) technologies. ADPs are associated with higher rates of return in manufacturing value-add and are driven mainly by faster productivity gains. Of particular interest is that the report shows that ADP technologies also present positive employment growth. As noted earlier, South Africa falls into that category of 'followers in use of ADPs' because of weak development in technologies and patents held. UNIDO advises that interventions are needed to shift – perhaps even push – the adoption and development of capabilities in ADP technologies to allow for 'catching-up' by developing economies. This takes us back to the observation made earlier that the proposed 'Sovereign Fund' as well as the 'Infrastructure Fund' are two instruments that are intended to achieve just that and that it may be necessary for the new ventures to be driven from the already established platforms that have developed these new capabilities. These platforms include the DST-NRF Centres of Excellence and other Specialist Centres at universities and research institutions. Table 4.9 outlines the distribution of university-based Research Chairs that are closely aligned to advanced manufacturing systems that are funded by the DSI through the NRF.

The CREST scientometric study on the state of South Africa's research enterprise[226] (referred to earlier in this report) illustrates the comparative field strengths across a set of prioritised science domains as shown in Figure 4.30 below. The CREST report confirms an observation made earlier in this report that there has been a decline in RDI capacity in engineering sciences between 2008 and 2016.

[225] Ibid.
[226] Ibid.

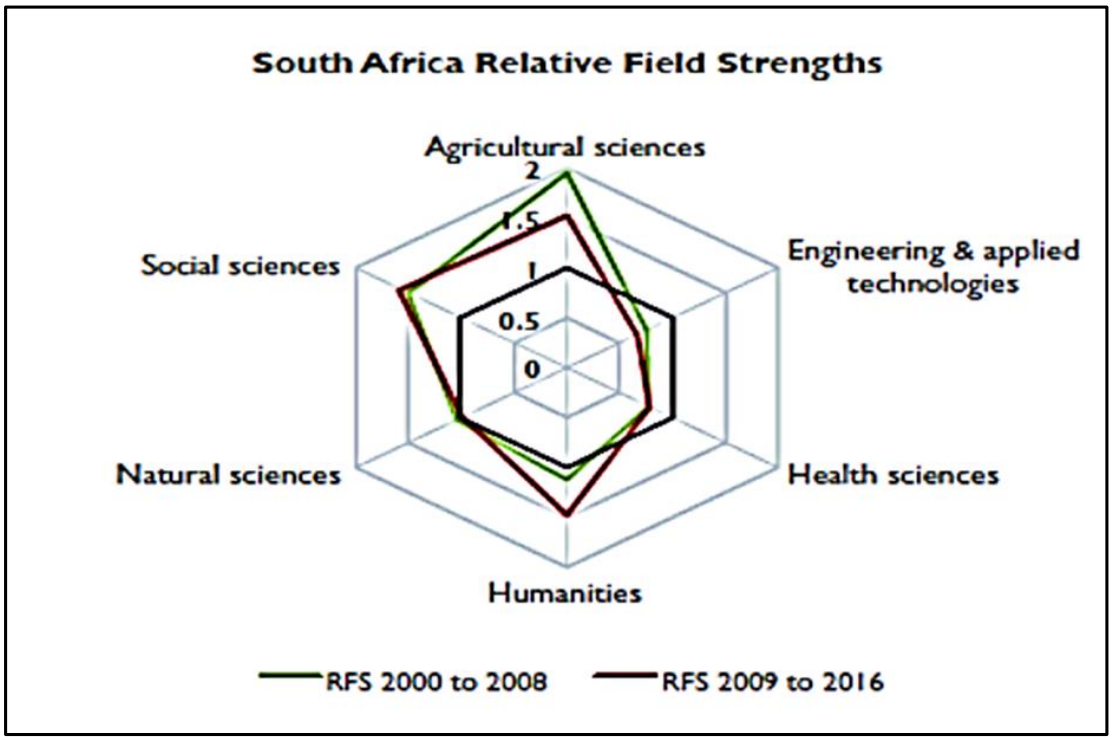


Figure 4.30: Relative strengths of science domains, 2000–2008 and 2009-2016

The existing industrial base

Some of the current industry associations

Engineering Council of South Africa (ECSA)
South African Institute of Electrical Engineers
Electrical Contractors Association of South Africa
South African Association of Consulting Engineers
Computer Society of South Africa
South African Institution of Mechanical Engineers
Chemical and Allied Industries Association
SA Capital Equipment Export Council
Automotive Industries Export Council
SA Aerospace Maritime and Defence Industries Association
Aerosol Manufacturers Association
Steel and Engineering Industries Federation of SA
South African Stainless Steel Development Association
SA Petroleum Industry Association
Plastics Industry Association
Oil and Colour Chemists' Association of South Africa
Cosmetic Toiletry and Fragrance Association of South Africa
The Beverage Association of South Africa
Pet Food Industry of South Africa
Water Meter Manufacturers Association

National Treasury

Development Bank of Southern Africa (DBSA)

DSI
TIA, SIF
CSIR, SANSA
Hydrogen Economy SA (HySA)
SKA
NRF – grant funding to university researchers
NRF Research Chairs

DPE
State-owned enterprises
Eskom
PRASA
SANRAL
DENEL
SAA
FOSKOR

SOVEREIGN FUND?

INFRASTRUCTURE FUND?

DTIC
Support Programme for Industrial Innovation (SPII)
Technology for Human Resources in Industry Programme (THRIP)
Manufacturing Competitiveness Enhancement Programme (MCEP)

South African Bureau of Standards (SABS)
National Metrology Institute of South Africa
National Regulator for Compulsory Specifications (NRCS)
South African National Accreditation System (SANAS)
The Design Institute of South Africa
Small Enterprise Development Agency

Industrial Development Corporation (IDC)

Industrial Development Zones (IDZs) and Special Economic Zones (SEZs)

Figure 4.31: A mapping of some of the key role-players in manufacturing

4.3.8 The Circular Economy

The conceptual framework for the circular economy is largely 'manufacturing and technology' based. The STI-WP provides a definition in terms of *'… looking beyond the take, make and dispose extractive industrial model towards the circular economy which is designed to restore and regenerate…'*.[227] Central to this, the conceptual framework of the circular economy is sustainable resources use and zero-waste, and this includes a focus on the environmental impact of industrial activity, consumption and waste management. The STI-WP furthermore notes that the circular economy is linked to the Sustainable Development Goals (SDGs) since it offers opportunities for economic growth in innovative business activity, services and job creation.

During the launch of the Africa Alliance on the Circular Economy, South Africa's official position was expressed as follows: "*… the Circular Economy avoids wastage of resources. It actually brings back the materials that would have been disposed of. It is important to note that the circular economy is the sustainable development model … it keeps resources at their highest possible level of value within the loop for as long as possible* …"[228] The recently published NACI Foresight Report[229] has proposed a comprehensive framework on both biological and non-biological waste streams that includes the following:

- Reducing, reusing and recycling waste;
- Ensuring sustainable water, energy and food (agriculture) security;
- Low-carbon and climate-resilient economy; and
- Smart connectivity and mobility in communities.

Noting the above conceptual frameworks, the objectives of the 'Circular Economy' should not be conflated with those of the 'Green Economy'. The latter is focused specifically on the development of renewable energy alternatives that target lower carbon emissions. Accordingly, in this review, the 'Green Economy' is deliberately discussed under the RDI for 'A Sustainable Energy Mix' (see Section 4.3.5 above). It is important to get the focus right and for this purpose the literature from the deliberations and working papers of the Organisation for Economic Cooperation (OECD) and the African Union (AU) provide well-informed insights on the circular economy and the envisaged impacts of transitioning to an economy with greater material resources efficiencies. This is particularly important for African countries that are still significantly reliant on primary minerals commodities for economic development and growth.

An OECD working paper on macro-economic modelling of the transition to the circular economy[230] sums up the transition to a circular economy as '*any process that might lead to lower rates of natural resource extraction and use'.* The working paper presents some important insights on this issue as captured below.

- Creating material loops: involves recycling products as virgin products or equivalents;
- Slowing material flows: involves the emergence of products which remain in the economy longer due to innovations and more durable product design;

[227] White Paper on STI 2019.
[228] Mrs Edna Molewa's Speech, 2017. Minister of Environmental Affairs: Speech at the launch of the African Alliance on the Circular Economy, 2017. Available https:www/dea.gov.za
[229] Ibid.
[230] Mc Carthy, A., R. Dellink and R. Bibas. 2018. The Macroeconomics of the Circular Economy Transition: "A Critical Review of Modelling approaches", *OECD Environment Working Papers, No. 130,* OECD Publishing, Paris.

- Narrowing material flows: involves the more efficient use of natural resources, materials and products, either through the development and diffusion of new production technologies, the increased utilisation of existing assets, or shifts in consumer behaviour away from material-intensive goods and services.

South Africa should be able, through technological innovations, to drive vibrant growth in new industries and employment when it invests in and develops the circular economy. For example, there are significant opportunities in the application of biotechnology and nanotechnology in the production of materials that will minimise resource usage and conversions for alternative or safer usage or disposal. Biotechnology also has uses in the disposal of plastic materials. In the area of advanced manufacturing, the use of precision machine-cutting, using nesting software, allows for strong gains in material usage for metals, wood and other materials. The environmental footprint of STI-based products and services is increasingly a consideration in consumer spending decisions. Consequently biotechnology, nanotechnology and other emerging technology areas should be supported with stronger science and technology societal outreach and awareness engagements through not-for-profit organisations, for example, and should form an important chapter of the work of the South African Agency for Science and Technology Advancement (SAASTA) or the new science engagement activities proposed in the STI-WP.

4.3.8.1 Socio-economic and environmental background

The State of Waste Report (SOWR) published by the DEA in 2018 reported that:

- In 2017 South Africa produced an estimated 42 million tonnes of general waste, of which only 11% was recycled. This was predominantly biomass from the sugar mills, sawmills, and paper and pulp industry, while 35% is denoted as 'other';
- In 2017 South Africa generated approximately 38 million tonnes of hazardous waste with only 7% re-used or recycled. Of note is that the remainder was either treated and/or landfilled; and
- South Africa imports and exports waste (paper, plastic, glass and metals), which is regulated by the Basel Convention[231].

Based on the distribution of waste management licences for waste management facilities, 82% is concentrated at landfills. Treatment facilities account for 11%, chiefly waste-water treatment works (WWTW) and facilities for Health Care Risk Waste (HCRW). Recycling and recovery facilities only account for 7% of licences. Some of the reasons for the lack of response and action by both producers of waste streams and businesses in the waste management industry have included the argument that virgin materials are cheaper than recycled products. The DEA in the 2017/18 SOW Report proposes levy and tax incentives/penalties as well as subsidies to offset this challenge. Another argument put forward for the lack of response and action is that volumes of recyclable material are small and impacts the economic viability of businesses. However, population growth, rapid urbanisation and increasing consumption will in the near future significantly impact waste production and use volumes.

Every effort must be made to reduce wastage in the production of goods and the provision of services, and far more must be done and urgently so to recycle and thereby limit waste disposal volumes. The DEA (now DEFF) uses a number of instruments to both regulate and incentivise all stakeholders to adhere to the directives of the South African National Waste Management Strategy (NWMS). The NWMS is centred on the Waste Act's hierarchy of objectives. These are presented in Table 4.10 below,

[231] Basel Convention.

in decreasing order of priority. All industry and business stakeholders are required to apply these objectives in making decisions on how to manage waste.

Hierarchy of priority objectives	Description of stakeholder requirements	Strategic instruments/mechanisms to support implementation
Waste avoidance and reduction	Goal is for goods to be designed in a manner that minimises waste components and reduces the quantity and toxicity of waste generated during the production process.	The NWMS recognises the key role of research and technology development and advocates that the R&D tax incentives should serve to influence the responsiveness of industry. It also recognises that the Technology Innovation Agency (TIA) has a role to play in this context.
Re-use	This removes the article from the waste stream for use in a similar or for a different purpose without changing its form or properties.	The NWMS recognises that the CSIR-based National Cleaner Production Centre is implementing the country's Cleaner Production Development Strategy with the support of the United Nations Industry Development Organisation (UNIDO). Of particular importance is that the Waste Act's Extended Producer Responsibility (EPR) provisions require industry to develop and secure approval for waste management plans that address all four dimensions of the waste hierarchy, that is, avoidance, re-use, recycling, recovery and disposal in broad consultations with municipalities and society.
Recycling	Includes separating articles from the waste stream and processing them as products or raw material inputs.	Industry waste management plans will be used to set targets, for example, for the pesticide industry, the lighting industry, the tyre industry and the e-waste.
Recovery	Involves reclaiming particular components or materials or using the waste as fuel.	As above.
Treatment and disposal	As a last resort, waste is to be treated and/or disposed of, depending on the safest manner for its final disposal.	Licensing will be used to regulate these business operations, particularly as it relates to hazardous waste.

Table 4.10: Waste hierarchy of objectives and strategic R&D-related response instruments

4.3.8.2 R&D investments and the research base for the circular economy

During the period of this review it was not possible to identify credible data that is specific to R&D investment in the circular economy. The same challenge affected data collection on the research base for this cluster. The industry is described as nascent in the DSI's roadmap for the national research community. Encouragingly, it has recently been recognised as a priority thrust/domain by the National Foresight Report. It is envisaged that the National R&D Survey will in future collect statistics on relevant RDI investments in this area.

4.3.8.3 Direction-setting and coordination

A substantive discourse on the circular economy in R&D commenced in South Africa only in recent years. Some elements have received considerable attention from government departments, research organisations and not-for-profit organisations. However, interventions are still in the early stages. DEFF plays a leading role, and waste management is of particular concern as is evident from the 2017 State of Waste Report (SOWR). There have also been legislative and strategic interventions in this area. The DEFF approach has targeted management of the end state – i.e., waste streams - by following the 3R doctrine of *reducing, recycling and re-using*. Much has been accomplished in policy related programmes packaged for implementation through the Phakisa coordination platforms, as

Figure 4.32 below illustrates. The role for the NSI is clear from these Phakisa directions, and goes beyond the traditional roles of the DSI.

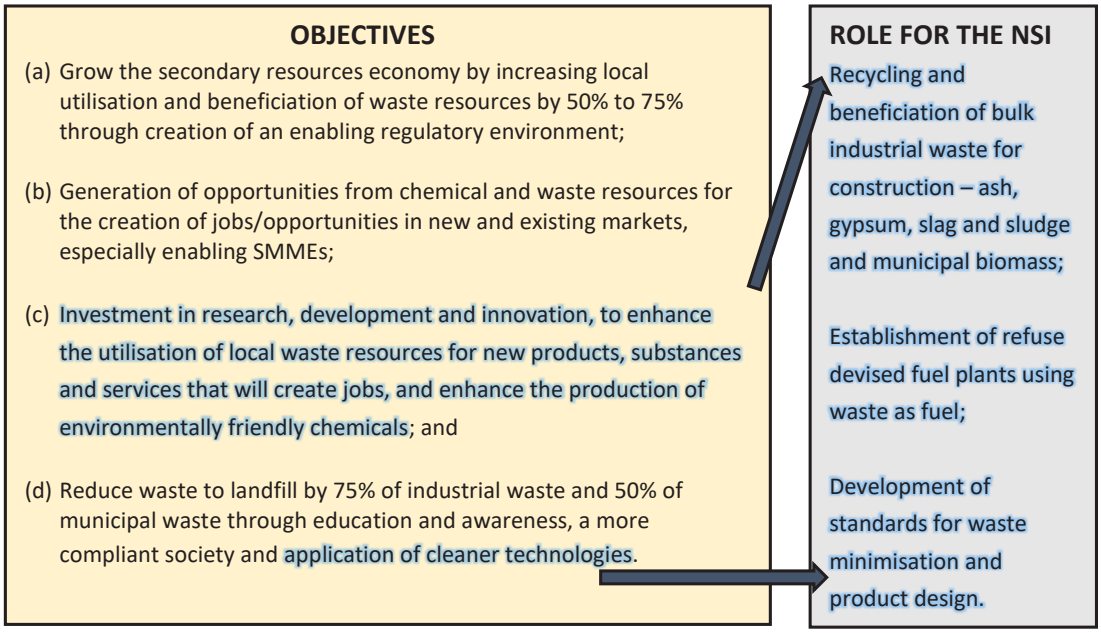


Figure 4.32: The Phakisa Chemicals and Waste Economy Lab

The role for departments such as the DSI should be centred on the production stage, i.e., the nurturing of technologies for narrowing/reducing material usage, or more broadly stated, technologies for more efficient production. The DTIC, in partnership with UNIDO, has been funding a programme at the CSIR called the National Cleaner Production Centre (NCPC). This has been the case since the 2002 World Summit on Sustainable Development. The NCPC is described as a national programme of government that promotes the implementation of resource-efficient and cleaner production (RECP) methodologies. These aim to assist industry to lower costs through reduced energy, water and materials use, and waste management. The objective is often described as 'lean or clean manufacturing'.

The sectors in which the NCPC has been active are aligned with priority industrial sectors. DTIC has taken the position as the full funding partner to the NCPC. To give stronger context to the greater ambition of research into new smart materials production, the DSI should support the efforts of the NCPC with material usage efficiency and waste management studies in each of the emerging technology research programmes. For example, 'life cycle assessments' in the titanium production and fluorochemicals industrial development programmes are underway. This leans towards managing the problem before it becomes a problem. Given the positioning of the 2019 STI-WP with respect to inclusive growth, there is an opportunity for STI to lead through technology diffusion as well as small business training through the NCPC. This can be undertaken in partnership with the technology stations that are located at most universities of technology.

The nature of the challenges in this area of the 'Circular Economy' do not point to a need for the creation of a new institutional RDI platform. Instead, it calls for recognising the existing platforms and growing them significantly to ensure that the NSI becomes far more active in reducing waste through both product design and manufacturing efficiencies. Figure 4.33 and Table 4.11 below profile some of the more prominent role players and university chairs that are active in the circular economy.

Government departments and municipalities and other statutory entities

- Environment, Forestry and Fisheries (DEFF)
- Provincial and local government
- Local municipalities
- Science and Innovation (DSI)
  - TIA
  - Global Change Grand Challenge
  - Climate Change Grand Challenge
- Trade, Industry and Competition
  - THRIP – triple helix
  - SPII
  - DBSA
  - IDC
  - MCEP – manufacturing enhancement
- Consumer Goods Council
- Health
- Mineral resources
- Energy - renewables
- Water Affairs and Sanitation
- Department of Higher Education and Training
- Department of Education

Scientific research institutions

- Council for Scientific and Industrial Research (CSIR)
  - National Cleaner Production Centre
  - Smart Cities Initiative
- SA Bureau of Standards (SABS)
- Technology Innovation Agency (TIA)
- Human Sciences Research Council (HSRC)
- National Research Foundation (NRF)
- Water Research Council (WRC)
- Academy of Sciences of SA (ASSAf)
- SA National Biodiversity Institute (SANBI)

Centres of Research Excellence and Research Chairs

18 NRF Research Chairs

Business

All state-owned enterprises (SOEs)

EnviroServ

Plastics Federation of South Africa

Not-for-profit organisations

World Wide Fund for Nature (WWF-SA)

Manufacturing Circle

Circular Vision (CE Network)

National Business Initiative

Green Cape

Figure 4.33: Organisations active in the cluster of the Circular Economy

UNIVERSITY	Engineering Sciences	Chemical Sciences and *Chemical Engineering	Social Sciences	Agricultural Sciences
University of the Witwatersrand	Sustainable Process Engineering			
University of the Witwatersrand	Hydrometallurgy and Sustainable Development			
Durban University of Technology		Development and optimisation of wastewater for developing economies		
North-West University		*Biofuels and other clean alternative fuels		
Stellenbosch University		*Biofuels and other clean alternative fuels		
Stellenbosch University				Sugar cane bio-refining
Stellenbosch University				Post-harvest technologies
Stellenbosch University			Social-ecological systems and resilience	
Stellenbosch University			Sociology of land, environment and sustainable development	
Stellenbosch University		Advanced macromolecular architectures		
Tshwane University of Technology		Water quality and waste-water management		
Tshwane University of Technology		Acid-mine-drainage treatment		

Table 4.11: NRF South African Research Chairs related to Circular Economy R&D

4.4 Performance measurement of the NSI

The purpose of the 2008 Ten Year Innovation Plan[232] was defined as *'helping to drive South Africa's transformation towards a knowledge-based economy, in which the production and dissemination of knowledge enriches all fields of human endeavour'*. Progress towards a knowledge-based economy is tracked through performance indicators that demonstrate the extent to which the share of high-value products and services in the productive output and exports of the country – that is increased value-addition – contributes to the GDP. A knowledge-based economy becomes more probable where the country possesses a highly qualified workforce and has high levels of scientific and engineering capacity.

The 2019 STI-WP recognises that constraints to effective functioning of the NSI have been identified in recent reviews and include inadequate high-level science, engineering and technology (SET) and technical skills for the economy, and an undersized research system. In effect, the transition to a knowledge-based economy proposed in 2008 has been limited. This is despite significant increases in transformation and growth in human capital in the fields of science and engineering. There has been limited growth in the number and size of STI entities, however, and the absorption capacity has not expanded adequately.

There are two extremely important dynamics to be considered in the ongoing work on the country's transformation to a knowledge economy. Firstly, as outlined in earlier and new policy and strategic plans of the DSI, the research enterprise should be expanded with increased expenditure on research and development (R&D) by both government and the business sector. The issue of where this expenditure happens is the subject of the NSI priorities discussed in earlier parts of this report where we address the idea of societal grand challenges or national priority thrusts. The second dynamic relates to monitoring and evaluation of the transformation path towards a knowledge economy. These are the quantitative performance assessment metrics that should inform government of the knowledge-based outputs that impact the economy. These are not only statistics that relate to expenditure on R&D but also include outputs such as patents and royalty income; licensing income; manufacturing performance and exports and related contributions to GDP; and the scale and intensity of high-tech service sectors. The Framework for Development of the STI Decadal Plan notes, in reference to the 2012 STIIL Review Report finding, that the STI measurement capacity is inadequately institutionalised.

The importance of the monitoring and evaluation of the NSI is recognised in the 2019 STI-WP that sets out that the National Advisory Council on Innovation (NACI) will be reconfigured to act as the national STI monitoring and evaluation institution, and that it will be charged with analysing STI information and undertaking work to inform government planning on STI. The 2019 STI-WP goes further to direct that NACI will draw on the work of existing specialist centres that collect STI-related information. These institutional arrangements and specialist centres will be maintained and strengthened and, where necessary, expanded. It is this planned trajectory that warrants the attention of this Review.

With decision-making by government, and industry and international investors very often dependent on the integrity of such performance indicators, it goes without saying that the source of such information should of necessity be based within an accredited professional institution. The type of indicators employed is also important. Within the developing-country context there have been arguments as to the appropriateness of development indicators where measurements of development that are important to the country are not in evidence. In this regard, the 2019 STI-WP notes that NACI will develop a composite South African Innovation Index that responds to the specific needs of the country. The overall performance of the NSI is currently assessed and reported on through, among others, the STI Indicators

[232] DST, 2008. *Ten Year Innovation Plan, Towards a Knowledge-based Economy*. Pretoria, DST.

Report produced by NACI. The sources for quantitative assessments of the NSI performance are currently identified in the 2017 NACI Performance Report on the NSI[233] and are set out as follows:

- Survey of the Inputs to Research and Experimental Development, following the Frascati Manual[234];
- Innovation Survey, following the OSLO Manual[235];
- Government expenditures on science and technology activities, following the UNESCO[236] definitions;
- Annual Reports (higher education institutions, science councils, listed companies, state-owned enterprises, non-profit organisations);
- Higher Education Information Management System;
- Reports of Statistics South Africa (StatsSA);
- Reports of the South African Reserve Bank;
- Reports of the World Bank;
- Reports of the UN System (UNESCO, UNIDO, UNCTAD, WHO and others);
- Reports of the Organisation for Economic Cooperative Development (OECD);
- Reports of the Offices of Technology Transfer (OTT) on the outputs from publicly funded research and experimental development; and
- Contributions to the literature from academic and other professional sources, e.g. *The state of the South African Research Enterprise* produced by SciSTIP, a DSI-NRF Centre of Excellence at Stellenbosch University[237].

This Review presents an opportunity to initiate the process of profiling the key centres and institutions that contribute towards the assessment of the performance of the NSI. The intention here is to provide decision-makers with information on those aspects that can influence decision-making on the institutional expansion or consolidation of activities for the optimal functioning of the NSI.

In order to support its advisory service to the Minister of Higher Education, Science and Innovation, the 2019 STI-WP recognises that NACI currently draws on the reports of CeSTII and other institutions as listed above. This aspect of the NSI relationships is critical as NACI's objective distance facilitates a rigorous critique of the findings of the CeSTII and other data-gathering institutions. The benefits of this objective distance are further enhanced with science-based analysis of the statistical reports by academics and policy experts. The question that arises is whether the current arrangements are optimal in serving the needs of government and other stakeholders or whether these should be expanded. In our view there is a need to revisit and question the future sustainability of the current DSI approach. It may now be the time to consider seeding the establishment of dedicated capacity for statistical surveys on research, technology and experimental development at the HSRC. The question of course is 'was DSI seeding' the development of capacity for the surveys or was it actually 'institutionalising' and giving CeSTII a mandate for the development of the longitudinal series of R&D surveys and related RDI performance-monitoring and evaluation studies. If this was the case, then it is timely to reinforce this mandate by designating CeSTII as a 'National Facility' since its long-term tenure could thus be clarified. Irrespective of the final

[233] NACI, 2017. *Towards a Next Generation Science, Technology and Innovation White Paper for South Africa, Performance Analysis*. Pretoria. NACI/DST.
[234] Frascati Manual.
[235] OSLO Manual.
[236] UNESCO STAs.
[237] SciSTIP, 2019. J. Mouton, I. Basson, J. Blanckenberg, N. Boshoff, H. Prozesky, H. Redelinghuys, R. Treptow, M. Van Lill, M. Van Niekerk. *The State of the South African Research Enterprise*. Published 2019: DST-NRF Centre of Excellence in Scientometrics and Science, Techology and Innovation Policy. Stellenbosch University. Available as an e-book.

decision on the institutionalisation of CeSTII, it is argued that a reconfigured NACI should be the ultimate focal point for the review and analysis of evidence-based advice to government on STI.

4.5 The role of SOEs in the NSI

4.5.1 Why SOEs matter in the NSI

The 2019 STI-WP rightly identifies state-owned enterprises (SOEs) as key role players in the development of the NSI. While SOEs are generally subsumed within the overall business category when analysing RDI data, this Review endeavours to disaggregate this data. This will allow for an analyses of the positioning of SOEs within the NSI in regard to the goals of the NDP. The NDP declares that "the national system of innovation needs to function in a coherent and coordinated manner with broad common objectives aligned to national priorities. The national system of innovation, the higher and further education system, SOCs [state-owned companies] and private industries should create a common overarching framework to address pressing challenges."[238]

It is self-evident that the changing world of economic transactions and trends is increasingly reliant on a range of knowledge and knowledge-based patterns of economic development. Because of the complexity of their mandates, the varied productive and solution-based clusters at their command and their ability to work and innovate at all levels of cognitive complexity in the national interest, SOEs are more than well-placed to assist in such necessary transitions.

SOEs operate in some of the key sectors underlying social well-being and economic prosperity in South Africa. This unique positioning means that they can and should play a key role in the achievement of the goals set out in the NDP. The mandates of SOEs moreover ought to stretch beyond being employers or nurturers of skills enhancement to participation in the expansion of the country's RDI infrastructure. As the country progresses to becoming a player in the global knowledge economy, so too SOEs – given their size, influence and real and potential impact – ought to participate in this world of know-how in partnership with science councils, higher education institutions and other research organisations. It is through the SOEs that sector specialisation can occur, technological deepening and upgrading can be achieved, and the adoption of advanced digital production technologies can come to serve the national good. Alongside that, they ought to encourage innovative start-ups and use their procurement capacity to catalyse local manufacturing value-chains. It is to this matter that - i.e. the capacity of the SOEs with respect to revitalising the NSI through research, experimental development and innovation aimed at meeting the targets set in the NDP – that we now turn.

One of the most direct methods of governmental economic intervention in the 20th century was the creation and use of SOEs to produce goods and services directly for public use. South Africa's SOEs had emerged from the need to develop local capabilities through import-substitution industrialisation. It formed part and parcel of an effort to move the country from a raw materials exporting economy towards beneficiation and industrialisation. Eskom, Iscor (now ArcellorMittal) and the South African Railways and Harbours (now Transnet) played a critical role in linking government ambitions and goals with the private sector, and with technology transfer training and innovation. In our view, the future roles of SOEs depend on their ability to reinvent themselves from years of mismanagement, malfeasance and corruption by expanding and intensifying investments in research and development, innovation and skills formation. It is only in these manners that they will become effective players serving the country's people in a globalising world.

[238] The NDP Vison 2030, page 289.

SOEs are of extreme importance throughout South Africa because:

- They are functioning in significant infrastructure and service industries such as water, energy, financial services, communications and transportation;
- These services are important to the welfare of all;
- Many South African citizens are employed by the major industrial sectors such as mining and textiles that depend on the services SOEs provide; and
- Some SOEs are funded by means of taxpayers' contributions.

Post-1994 a small number of SOEs were privatised, others were partially privatised (e.g. Telkom and ACSA), while many received no state income. Through restructuring, competition and privatisation, the intention was to reduce the role of government in these industries and have regulatory oversight to ensure the efficient development of these industries and the downstream sectors which depend upon them. Due to the high-profile financial difficulties experienced by several SOEs including Denel, Eskom and Transnet, the role of SOEs in the economy has once again become the subject of much debate. While the financial sustainability of SOEs is important, it is useful to also review their role in modernising the economy through innovation, developing the skills base and their impact on socio-economic outcomes.

The four largest SOEs – Eskom, Transnet, Denel and Telkom – are also technology and R&D intensive and should invest far more in RDI, both financially and in terms of human capacity and capabilities, in order to maintain competitiveness and their leading-edge innovation. More importantly, Eskom, Transnet and Telkom provide essential services that are fundamentally linked to the quality of life and well-being of the country's citizens. Denel too engages in peace-making and peacekeeping on the continent and beyond, and there is great potential to pivot from military applications of technologies to focus its RDI on civilian innovations such as search and rescue and geo-mapping. The point is that RDI matters, but even more so for many SOEs because they are intrinsically linked to the ways in which most citizens live their lives.

4.5.2 Performance of SOEs in R&D

As pointed out in the previous chapter on Situational Analysis, SOEs have forfeited their leading role in the NSI since the advent of democracy in 1994. The National R&D Survey data and other indicators reveal unflattering SOE trends such as:

- SOEs are spending less on R&D and have reduced their share of the total BERD;
- R&D tends to be focused on technical improvements and efficiency gains;
- Governance and leadership instability and failure shifted the focus of SOEs to financial performance and sustainability only;
- Whereas pre-1994 SOEs were renowned for developing technical and artisanal skills, SOEs are now focused on international recruitment (see case studies below);
- The number of SOEs with a significant level of R&D has dropped from 21 in 2009/10 to 16 in 2017/18; and
- The distribution across R&D types has been 5.6% in basic science, 74.4% in applied sciences and 20.1% in experimental sciences.

These observations will be unpacked in greater detail. However, it is important to highlight the concern about the decrease in investment in research in the field of engineering sciences within the business sector due to the sharp decline in SOEs investment. We concluded that this decrease shows a strong correlation with the rapid decline in the performance of the SOEs during the period of 'state capture'. As noted, opportunities now available for the turnaround of SOEs should see them recommit to and re-

invest in RDI, thus enabling the country to scale up RDI investment to the national target of 2% of GDP. Such a commitment would contribute to SOEs playing a leading role in enlarging the country's RDI capacity.

There is sufficient evidence of the sharply declining R&D activity of SOEs [239], and "[t]he largest four South African SOEs (Eskom, Transnet, Denel and Telkom) account for 91% of the assets, 86% of the turnover and 77% of the total employment of SOEs. Denel, Armscor, Transnet, Telkom and Eskom – all of which are considered key entities for economic development under the new strategic path – contribute 99% of all R&D performed".[240] There is also evidence of bottlenecks resulting from skills gaps, and inadequate data available to properly assess SOEs external linkages, the current state of their capabilities and their future R&D needs.[241]

South Africa's ratio of nominal fixed capital formation to nominal GDP declined to 17.9% in 2019 – the lowest level since 2005. The private sector's share of total nominal gross fixed capital formation nevertheless increased slightly from 68.5% in 2018 to 70.0% in 2019, as budget constraints negatively impacted capital spending by SOEs and general government. The latter declined from 31.5% in 2018 to 30.0% in 2019. The issue of capital flight is pervasive, and its negative effects cannot be overstated. It greatly limits the choices of government and bodies such as the SOEs and contributes to spending priorities being focused on short-term necessities. As a result, R&D and innovation, necessarily focused on a longer-term time horizon in terms of potential benefits, take a backseat. It is therefore unsurprising that R&D levels in SOEs have shrunk in the recent past.

Figure 4.35 shows that in 2008/09 SOEs spent 32.9% and 59.6% of their R&D expenditure on applied and experimental research respectively. However, by 2017/18 the pendulum had swung completely to the opposite extreme, with SOEs spending 74.4% and 20.1% on applied and experimental research respectively. This reallocation of R&D expenditure to applied research highlights the focus of SOEs on efficiency and performance rather than on experimental innovative solutions.

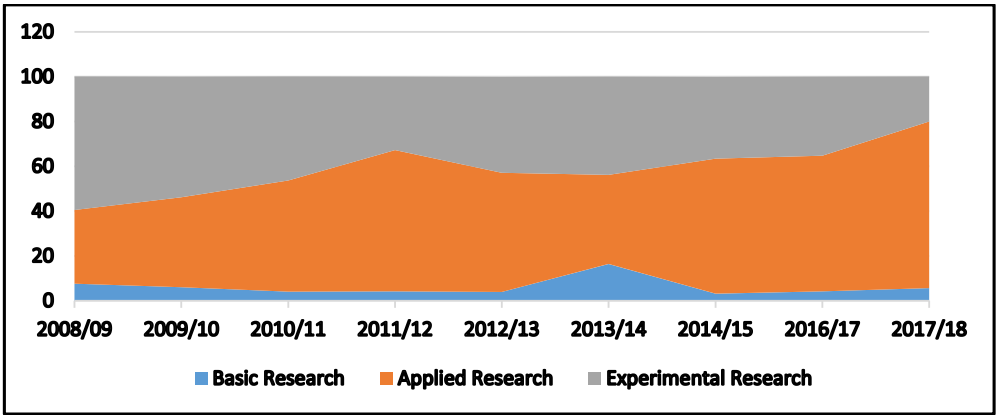


Figure 4.35: SOEs R&D distribution across types of research 2008/9-2017/18[242]

[239] Mustapha, N, G Kruss and G Ralphs. 2018. The future of state-owned enterprises in South Africa: Why R&D matters. *HSRC Policy Briefs*. Accessible at: http://repository.hsrc.ac.za/bitstream/handle/20.500.11910/11801/10252.pdf?sequence=1&isAllowed=y.
[240] Ibid.
[241] Ibid.
[242] Source: National R&D Survey 2017/18: HSRC/Center for Science, Technology and Innovation Indicators (CeSTII) (2019).

It is worth noting that of the 7 142 researchers in the business sector, only 21.1% are employed in SOEs. Figure 4.36 shows the full-time equivalents of R&D personnel. Researchers are R&D personnel engaged in the conception or creation of new knowledge, products, processes, methods and systems and in the management of the projects concerned. Full-time equivalent (FTE) is an estimate of the time spent on R&D activities and is specifically related to the proportion of time spent on R&D activities out of all time spent at work. There has been a significant decline in FTE researchers from 915.8 in 2009/10 to 668.6 in 2017/18. R&D personnel have also declined from 569.3 in 2008/09 to 119.6 in 2017/18. These are all persons (irrespective of nationality) employed directly in R&D, as well as those providing direct services such as R&D managers, administrators and clerical staff.

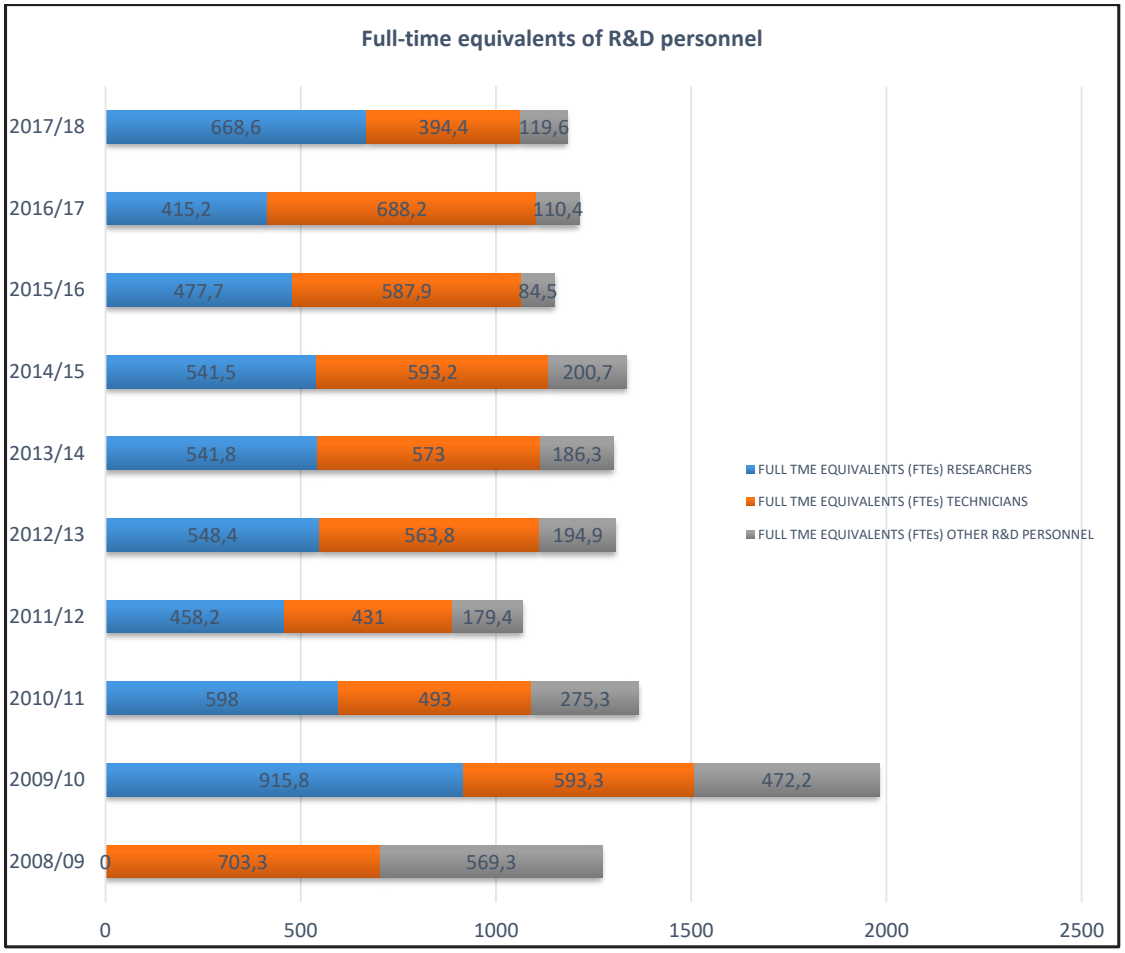


Figure 4.36: Full-time equivalents of R&D personnel in SOEs[243]

What the evidence does show (Figure 4.36), is that the number of technicians at SOEs has been growing since 2011/12 while the number of researchers engaged in R&D has been declining. This may suggest a focus on immediate operational priorities rather than on experimental and innovative research.

4.5.3 Key review issues on SOEs

[243] Source: Centre for Science, Technology and Innovation Indicators (CeSTII), 2019.

The recent establishment of the Presidential State-Owned Enterprises Council (PSEC) to support government's plan to reposition state-owned companies as effective instruments of economic transformation and development underlines the need for SOEs to reclaim their place in the country's economy. The PSEC's mandate includes strengthening the framework governing SOEs including the introduction of overarching legislation governing SOEs. It also is mandated to determine an appropriate shareholder ownership model. It will endeavour that SOE-specific interventions are implemented to stabilise companies through the strengthening of their governance, addressing their immediate liquidity challenges and implementing agreed turnaround strategies. Furthermore, its mandate will extend to a review of the role and mandate of SOEs to ensure a positive socio-economic contribution and alignment to the national development agenda. The PSEC will also review SOE corporate plans to ensure alignment to government priorities and to ensure appropriate systems are in place to monitor implementation of such plans. It will also monitor the operational and financial performance of SOEs, review their business models, capital structure and sources of financing, and mitigate risks.

All these aspects of the mandate of the PSEC will provide opportunities for reviewing the role of the SOEs in advancing RDI given that they are key role players within the NSI.

Further issues that flow from our analysis include:

- *Incorporate coherent and comprehensive system-level agenda and priority setting to fully realise the social and economic benefits from STI* – SOEs have forfeited their roles as key actors within the NSI with participation in R&D declining across all key measures. A comprehensive, targeted and consolidated programme of action is needed to gain back the ground lost to 'state capture' and a blinkered short-term outlook. The appointment of boards and executives, furthermore, should take into account the presence of engineering competencies and include an appreciation of the importance of R&D for the performance of the enterprise.
- *Stimulate and deepen domestic technology transfer and industrial innovation* – The state, through SOEs, can achieve this by setting aside a percentage of the procurement spend for promoting local innovation.
- *SOEs need to play a decisive partnership role if the main missions we have outlined in this report are to be achieved*: The quality of life and well-being envisaged in our Report can and ought to benefit from breakthrough research and development in and through, for example, the work of Transnet and Denel; the Climate Crisis/Change priorities for a shift to a 'green economy' should benefit from Eskom's influential role; the challenge of Livelihoods in a Changing Technological World should benefit from the influential roles of Telkom and Denel; and Education for a Future Society can be enhanced by well-focused partnerships with the post-school system from digitally simulated environments and working worlds to new data-savvy innovations.
- *SOEs should play a much more prominent role, in close collaboration with the TVET sector, in the development of key technical skills for the economy.* The SOEs can provide an important link between workplace experience and skills development, and in enhancing practical and job-focused research and problem-solving.

Case study on the importance of coordination in the NSI: South African Automotive Industry

The SOEs and all other entities in the NSI should be aligned in order to harness the full innovative capacity of the system. The South African Automotive Industry is a case study of how major opportunities could be lost when there is no coordination within the system.

CASE STUDY 1: SOUTH AFRICAN AUTOMOTIVE INDUSTRY

Political efforts to align the post-apartheid democratic South Africa to international trade and trade policy facilitated the change to a globally competitive motor industry market. The Motor Industrial Development Programme (MIDP) of 1989 and 1995 undergirded these reforms and increased levels of specialisation. It also increased exports from R443 million in 1989 to R45.6 billion in 2005 and R88.8 billion in 2012. However, the import-export policy adversely affected locally produced content and increased foreign ownership of the industry.

The South African Automotive Masterplan's vision toward 2035 entails "a globally competitive and transformed industry that actively contributes to the sustainable development of South Africa's productive economy, creating prosperity for industry stakeholders and broader society."[1] Key to this vision are four proposals:

- The development by 2035 of a globally competitive industry.
- Contribution to transformation through employment equity and inclusion of black-owned firms within the automotive value chain.
- Promotion of sustainable development; and,
- Enhancing the economy.

The industry aims to "stimulat[e] the [electricity vehicle] EV market and develop an E-mobility value chain…a thriving EV market supported by local manufacturing holds the promise of economic growth and job creation. It will also counteract the demand for internal combustion engine (ICE) vehicles globally."[2] It is aimed at creating 'a living lab' – an ongoing R&D strategy to enable South Africa to keep abreast of developments and innovations.

Linkages: National innovation surveys have revealed that only a few SA firms are collaborating with universities or research centres, and that foreign firms "might have a higher propensity to engage in such collaboration."[3] A limited number of universities, science councils and firms are integral to the innovation systems in original equipment assemblies and components such as:

- University of the Western Cape – lithium ion cell manufacturing;
- uYilo e-mobility Program[4] – lithium ion cell testing protocol;
- CSIR – cathode materials using SA intellectual property and raw materials; and,
- Metair – use case for the final product.

Research and Development: The industry's participation in R&D in SA has a limited footprint.[5] R&D is generally focused on the development of components and electronic vehicles. Development of research niche areas in batteries and materials technology alongside nanotechnologies will become important for enhancing research in this area.

Absorptive Capacity: There many constraints that limit absorptive such as insufficient skills in the market and ancillary services to adapt to the growth of EV manufacturing; technicians need to be upskilled to facilitate transition toward electric mobility; training is also important for first-level emergency responders, dealerships and after-market services.[6]

Local and Foreign Direct Investment: The South African National Energy Development Institute (SANEDI) maintains a database of funding sources relevant to the industry. The Department of Trade and Industry and Competition facilitates local funding and aids local R&D and innovation. Foreign capital flows, especially FDI from numerous automobile companies[7] operating in SA,[8] enable optimal performance of the industry locally and globally.

Preferential Procurement: A key development in the Preferential Procurement Policy Framework Act[9] is the preferential inclusion of the automotive sector.[10]

Lessons: The following challenges[11] impede the development of industry innovation systems:

- Lack of coordination and foresight in the policy and regulatory framework, and its relations to R&D, innovation, commercialisation and industrialisation adversely affect the NSI and industry expansion.
- Insertion of the industry into the global mainstream of vehicle manufacturing highlights valuable analytical lessons for automotive economies in developing countries.
- The benefits of engaging in global value chains are clear, but long-term sustainability remain in question.[12]
  - The sector has proven susceptible to liberalisation policies and "the privatisation of state corporations led to substantial de-industrialisation."[13]
  - SA has a low share of manufacturing consumption versus manufacturing production.
  - The costs of trade diversion "are particularly high given the large presence of low-priced second-hand cars in most national markets."[14]
- Weak manufacturing capabilities, poor infrastructure[15] and the paucity of local content and/or indigenous manufacturing firms combined with flooding of used vehicles from countries of the global North and Japan have become a challenge for manufacturing industries.[16]
- Limited local content negatively affects innovation and development of technical knowledge and expertise.
- In the regulatory and policy context there is no coordinated approach to stimulating the EV market and promoting the local industry.
- There seems to be a disjuncture between higher education sector output and labour market demand in private sector innovation systems. There is a greater danger that the R&D work and the innovation systems of universities are not aligned with the innovations required and that the skills sets or competencies are declining instead of increasing.
- The incongruities between the technological capabilities and the innovation potential of SA firms and national support infrastructure require redress to create competencies that resonate with global competitiveness.
- The industry should develop fully functional, independent testing and associated verification capabilities. It should also simultaneously identify and nurturing more advanced R&D capabilities in selected automotive engineering fields.

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1 Barnes, J et al. 2018. Geared for Growth South Africa's Automotive industry Masterplan to 2025, Department of Trade Industry
2 Green Cape, Electric Vehicles 2019 Market Intelligence Report in https://www. Electric-vehicles-market-intelligence-rerprot-web4 / and https:// www.greencape.co.za
3 Buys, Andre. 2010 Ownership and Innovative Behaviour: The Case of the South African Automotive Component Manufacturing Industry in https:// www.buyspaper.pdg (research Aid)
4 uYilo E-Mobility Program 2017. Sustainable Transport and Mobility for Cities Workshop-eThekwini Municipality available at https://www.sanedi.org.za
5 Barnes, J et al. 2018. Geared for Growth South Africa's Automotive industry Masterplan to 2025, Department of Trade Industry
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7 National Association of Automotive Component and Allied Manufacturers cited in Lawana, N. The Impact of Foreign Direct Investment on Labour Productivity of the Automotive Sector in South Africa 2016 Unpublished Master of Science in Economics Theses in https://www.university of FortHare
8 de Bruyn, Chanel. 'BAIC investment into South African Vehicles Assembly Project Bolstering Bilateral Investments' in Engineering News November 2017, 28 in http://www.engineering news.co.za
9 National Treasury 2012. Invitation and Evaluation of Bids based on a Stipulated Minimum Threshold for Local Production and Content for the Bus Sector in http://ocpo-treasury.gover.za
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12 Barnes, Justin and Morris, Mike. Staying Alive in the Global automotive industry: what can developing economies learn from South Africa about linking into the global automotive value chains? Also available in https://www.springer.com
13 Black et al. Africa's Automotive industry: Potential and Challenges working paper Series No 282 September 2017 African Development Bank
14 Black et al. Africa's Automotive industry: Potential and Challenges working paper Series No 282 September 2017 African Development Bank
15 Black et a.l Africa's Automotive industry: Potential and Challenges working paper Series No 282 September 2017 African Development Bank
16 Black et al. Africa's Automotive industry: Potential and Challenges working paper Series No 282 September 2017 African Development Bank

4.6 The role of international cooperation in shaping the HESTIIL

International cooperation in RDI has played an important role in South Africa's policy regime since 1994. During the period of international isolation, the development of local capacity in RDI was constrained, even though some capabilities were developed owing to sanctions. The dawn of democracy created opportunities and challenges to reverse the adverse effects of isolation and establish new relationships that would support the growth and development of local innovation capacity.

South Africa's post-1994 bilateral and multilateral science diplomacy has been able to support the NSI in four key aspects. These are:

- International resources for STI
- Knowledge and technology transfer
- Benchmarking and best practice
- Promoting the African agenda

The DSI international cooperation programme has been geared towards leveraging the above and have produced some notable returns. In the context of this review, we highlight those that have had an influence in advancing collaboration and coherence in the local HESTI institutional landscape.

The DSI has played a pivotal role over the years in bringing about a flow of resources for science and technology into the country. During the 2018/2019 financial year, the DSI reports that R517 million in international funds was directly invested in local RDI programmes, including people development and infrastructure investment. Big science infrastructure programmes, such as the SKA, have helped to leverage important partnerships across the world to develop locally based infrastructure that is of international importance. Apart from the investments in infrastructure, years of strategic engagement with key networks, such as the European Union, have given local researchers and institutions favourable conditions to bid for competitive programme funding.

Science diplomatic efforts have also been instrumental in opening opportunities for individual South African researchers and institutions to forge global partnerships. The DSI reported over 700 partner organisations that have formalised arrangements with South African entities for STI and human resource development programmes. These kinds of partnerships have also benefited human resource development in that over 1 470 South African students have received training at a postgraduate level in STI programmes that directly derive from international cooperation.

The growth of cooperation in STI has been phenomenal on the African continent since the end of apartheid. STI cooperation has contributed significantly to driving the overall agenda for African development and integration under the auspices of the Southern African Development Community (SADC) and the African Union (AU). Programmes in astronomy, space science, marine biology and other environmental sciences are some of the opportunities that have been used as platforms for cooperation. Through bilateral and multilateral cooperation programmes, the case for STI as important foundations for Africa's development has received much attention.

An area that should not be overlooked in evaluating the impact of STI diplomacy on the South African HESTI landscape is benchmarking. While the local history, context and needs are duly foregrounded in policy-making, the country has taken advantage of international networks in the context of the European Union, the OECD and the BRICS for benchmarking. The meaning and targets of STI indicators that are used to guide policy and monitor progress, have benefited immensely from OECD resources and experiences. The BRICS offer benchmarks and frames of reference that are much closer in terms of a developing world perspective. In addition, there are innumerable opportunities that these relationships

create for institution-to-institution learning and cooperation for local research entities and universities. At a policy level, the close relationships provide learning opportunities for acquiring knowledge about how STI systems can be organised. Some of this knowledge has been utilised in this report, for example in informing the proposed coordinating mechanisms.

What is most significant for this review, is how international cooperation and resources have contributed to shaping the local HESTI institutional landscape. The South African Radio Astronomy Observatory (SARAO) is a good example of the effect that a significant international S&T cooperation programme can have on the organisation of the local system. South Africa's successful bid to co-host the Square Kilometre Array (SKA) radio telescope has fostered a positive dynamic in radio astronomy in South Africa. SARAO ensures a strategic management and coordination of all radio astronomy initiatives and facilities in South Africa, including the MeerKAT Radio Telescope in the Karoo and the Geodesy and Very Long Baseline Interferometry (VLBI) activities at the HartRAO facility in western Gauteng. SARAO does this while also spearheading South Africa's contribution to the infrastructure and engineering planning for the SKA.

There are other examples of how international cooperation initiatives have led to positive dynamics in the local STI system. Partnership programmes in postgraduate training have fostered closer DSI/DHET interfaces. The European South African Science and Technology Advancement Programme (ESASTAP), which was developed to coordinate cooperation between South Africa and the European Union, has helped to galvanise greater cooperation and coordination locally. Some of the curriculum innovations and partnerships in mathematics education among the participating universities in the Western Cape, came about in the context of the African Institute for Mathematical Sciences (AIMS). There is no doubt that STI internationalisation has had a considerable contribution to the local HESTIIL, and this should be expanded and deepened.

4.7 Issues and findings on NSI capacity analysis

Following the extensive discussion on the institutional capacity analysis of the NSI, we provide below the issues and findings that emanate from the Review.

1) The HESTIIL should be expanded and intensified to accommodate the aspirations of the country and the research careers of young people. As we move towards a knowledge-based economy, all NSI sector focused, and science and technology intensive government departments should have priority RDI areas which should be funded adequately but coordinated as outlined in the 2019 STI-White Paper.

2) The existing NSI capacity has been developed chiefly through the support from the Science and Technology Missions introduced in 2004, and the Grand Challenges introduced in the 2008 Ten Year Innovation Plan. These are still relevant and should not be abandoned.

3) There is considerable investment and research (over 7% of gross expenditure on R&D) in the field of environmental sciences involving the participation of multiple stakeholders across a range of industry sectors, government departments and research agencies, universities and non-profit research organisations. However, this Chapter has shown that despite the expansive and rapidly growing RDI activity in the environmental and marine/earth sciences cluster, there is no coordinating environment-marine and earth sciences council. The current extensive but fragmented research activity in this field is sub-optimal; and does not inspire confidence, nor does it stimulate the career aspirations of the growing pipeline of master's and PhD graduates. The cross-cutting stewardship and oversight mandate is recognised in the role of the former Department of Environmental Affairs (now DEFF), but the research intensity in both the basic

and applied research fields in the environmental sciences warrants that research coordination that is led by the DSI, ideally under a new environmental and climate change research council. It is envisaged that such a new research entity would fall under the umbrella of the proposed National Foundation for Research and Innovation as detailed in our recommendations.

4) The capacity analysis of the NSI confirms that public-funded centres and programmes across a number of science councils and universities are fragmented. Of concern is that significant funds have been invested in research infrastructure such as ocean-going vessels, mini research submarines, robotics and others that warrant a consolidation and focus on the key aspects of marine and Antarctic research. The 2016/17 STI Institutional Review recommended that the DSI proceed with the establishment of a number of new public research institutions. Among these is a marine and antarctic research institution that consolidates the research and investments that have been made by government and optimises the coordination of a range of stakeholder research interests across the higher education sector, government, business and non-profit entities.

5) In order to reach the NDP Vision 2030 desired outcomes, RDI capacity would have to be scaled up with a purposeful prioritisation of research and researcher growth in critical areas with explicit socio-economic-relevant outputs. The role of Post-School Education and Training (PSET) is paramount across four critical domains: (i) developing the next generation of researchers; (ii) providing the high-end skills required by the economy; (iii) responding effectively to societal needs; and (iv) strengthening and maintaining the relatively small but world-class research base that is evident across all the HESTIIL clusters. To achieve all these goals simultaneously will require that a fine balance is maintained.

6) The indications across all HESTIIL Clusters suggest that there is *project-level collaboration* within several DSI-NRF Centres of Excellence and South African Research Chairs, but not at a significant level. This capacity is also widely dispersed across the HESTI landscape and there is no major programme that provides structure and momentum for galvanising and driving integration of effort across the breadth of the NSI towards achieving the NDP objectives. This concern must not be confused with the role of the NRF which, by virtue of its funding mandate primarily for basic research, is not designed for intensifying applied research and achieving follow-through in terms of innovation and commercialisation. On the other hand, innovation and commercialisation is not the preserve of TIA alone. Consequently, the Review Panel motivates for the creation a new body, an overarching corporate research entity, to develop and maintain support for all NSI research councils, research funding agencies, technology transfer, innovation and commercialisation incentives and very large national research programmes that harness competencies specifically for NDP-related missions.

7) Research organisations such as Mintek and NECSA have demonstrated success in realising the commercial gains of intellectual capital derived from years of RDI. Many of the science councils that were interviewed during this Review voiced strong concerns about their significant limitations to spin out results into commercial outcomes or service offerings for the advancement of government service-delivery challenges. This matter will require urgent remediation.

8) In terms of published research outputs and the range of research chairs at universities and other non-profit research organisations, the medical and health system appears to be flourishing, however evidence suggests that the research outputs are not finding traction in the development of the healthcare system.

9) The business sector investment in ICT R&D, excluding SOEs, is very high at about 70% of total ICT R&D investment for 2016/17. This R&D investment performance has been consistent over the past ten years. Government investment on the other hand has been disappointing, except for the investments in ICT infrastructure by the Department of Science and Innovation. Serious performance failures that are linked directly to government service delivery can be remediated through targeted investments in smart information systems.

10) Despite a growing investment by the DSI in ICT R&D infrastructure, the expenditure on operational research costs is not increasing. This directly impacts on the ability to expand the research base and the employment of higher numbers of researchers. The purpose of the infrastructure is for research activity, but this is only possible if there is a reasonable outlay for research activities.

11) Coordination across the energy research thrust is extremely weak. This economic sector has been held hostage to 'state capture' in terms of both the hollowing out of the capacity of the state utility Eskom and the processing/roll-out of renewable energy investment agreements. A consequence of this has been the decline of the RDI enterprise in terms of the platform of scientists, engineers and technology.

12) There has been a strong DSI drive towards a 'Hydrogen Economy' that has seen significant research investments and collaborative engagements put in place across sectors and organisations. What is of concern is that there is no clear roadmap to commercialisation that has the solid buy-in of National Treasury and other key stakeholders, and every effort must be made to ensure that this excellent national effort succeeds, unlike the 'failed Joule'. Furthermore, the importance of rolling out the infrastructure for such a hydrogen economy must not be overlooked, even though some of this lies much further upstream in the mining sector.

13) The funding for RDI activity is sub-optimal and fragmented in some research fields in the DSI programmes and those of other departments, such as the South African National Energy Development Institute (SANEDI) of the Department of Mineral Resources and Energy.

14) Other reviews have drawn attention to the need for impact studies on the range of investments and interventions made to reduce hunger, malnutrition and poverty. It is in response to these concerns that we propose the establishment of a societal grand challenge or mission of 'Nutrition, Food Security and Food Sovereignty' rather than one that is focused on the narrower discipline of agriculture. The proposed catalytic societal grand challenges or missions are further discussed in Chapter 6: Key issues and findings.

15) It is noteworthy that the RDI platform in the agricultural sciences and food security cluster has not grown over the past two decades. What is cause for concern is that the strongest platform, the Agricultural Research Council (ARC), has an enormous challenge in terms of an ageing research workforce. As a consequence, science and engineering expertise has had to be contracted back post-retirement. The ARC has successfully supported industry and households and is on par with its international counterparts.

16) Investments in advanced manufacturing, materials and process technologies are suboptimal. Our review shows that it is only in pharmaceuticals and transport where South Africa features in the use of (*not leadership*) of technology-intensive and digital technologies for manufacturing.

17) Corruption has been at the heart of the country's failure to leverage state procurement for strengthening, expanding and diversifying local manufacturing. There is also a paucity of

engineering and scientific capacity within government departments – from national to municipal – and across to SOEs, and within executive and procurement management. This has adverse implications for the achievement of government efficiencies and innovation.

18) With its billions of Rands invested in products, components and services, SOEs were expected to lead a massive local supplier-development drive. While the opportunity to achieve this goal is still there, the level of trust in the SOEs has been significantly eroded. Much greater transparency will be required to establish bona fide targets and plans to lead and drive innovation and localisation of manufacturing.

19) The nature of challenges in the emerging Circular Economy do not point to a need for a new institutional platform. It is, however, a critical area for RDI investment, as is evident from the significant RDI investments made in Europe and elsewhere. There is an opportunity to grow the country's research capacity and technologies rather than depend wholly on foreign developments.

20) International cooperation in STI has resulted in the generation of significant resource inflows into the country. Significantly for this review, some international partnership programmes have inspired organisational changes and increased collaboration within the NSI. The SKA, ESASTAP and AIMS are examples of international programmes that have given rise to positive organisational dynamics within the local HESTIIL.

Chapter 5

Institutional landscape mapping

5. Institutional landscape mapping

5.1 Introduction and scene setting

The purpose of this chapter is to describe the country's national system of innovation using, among other methods, a diagrammatic depiction of its institutional landscape. This is intended to explore the adequacy of the HESTI institutional landscape and to describe its key features. This mapping and description of the institutional landscape serves to explore and to bring to the surface those factors that are deemed to constrain the optimal performance and effectiveness of the NSI. According to the STI-WP, these factors include "inadequate and non-collaboration in STI agenda-setting for the country, insufficient policy coherence and coordination, and weak partnerships between NSI players".

A full description of the approach and methodology of this section of the review is outlined in Chapter 2, and includes the following approaches:

- Landscape mapping of the NSI;
- Scientometric assessment of the system;
- Stakeholder opinions and suggestions; and
- Case studies.

The findings and recommendations that emerge from this chapter were arrived at through a process of triangulation involving the above methods, as well as several iterations of critical discourse analysis by the members of the Review Panel. A more detailed report of this work is found in the comprehensive report on Institutional Mapping at **Annexure C** to this Review Report. This chapter draws extensively from the same source to present the main data and summarise the salient issues, findings and recommendations.

Given that the key issue at the core of this HESTIIL Review is the lack of coherence and collaboration within the NSI, the importance of the institutional design provides a good starting point. For this purpose, we draw lessons and insights from international examples.

5.2 The importance of institutional architecture

It has been argued that structure provides the arena wherein actions take place[244]. In a sense, the organisational structure of the NSI is analogous to the design of a ship. As the vessel's design determines its speed, capacity and ability to withstand rough seas, so does the organisational structure of the STI system. As a policy instrument, structure aims to achieve specific objectives. Hence, objectives should be identified in advance, or concurrently with the development of a structure.

An important challenge is that structures are often the incidental consequences of political impulse and fragmentary approaches. Far too often the important attributes of structures as policy instruments are either ignored or made secondary to other objectives, and as a result any prospects of a system to fully realise its promise and purpose are limited from the start. Many years down the line, no amount of effort, resources injection or policy measures can ameliorate such a system malfunction. That is, unless and until the flawed institutional design that lies at the heart of the system failure is repaired.

[244] Pouris, A. 1995. Towards a metric of organisational structures for S&T policy: the concept of "Science Policy Space". *South African Journal of Science* 91:489-492.

This issue is exaggerated in countries such as South Africa that follow a pluralistic system of science, technology and innovation policy. In a pluralistic system each government department/ministry allocates its own budget according to its own assessment of needs. Research and innovation may or may not be part of the funding modes of those organisations. Similarly, a government department or ministry may decide to establish research-performing or science advisory units without taking into consideration the broader system of innovation. Over time, as these random and uncoordinated institutions proliferate, their uncoordinated and turbulent influence in the economy and society becomes impossible to ignore.

It arguable that the most important deficiency of a pluralist system is the absence of a champion that promotes the well-being of RDI across governments. Consequently, when government departments are faced with the inevitable budgetary cuts, they dial down their expenditure on RDI, with long-term consequences. In these manners then, the random evolution of the structure is reinforced.

The critical importance of the organisation of a country's RDI landscape is demonstrated by a recent OECD study conducted in 35 countries[245]. Figure 5.1 below shows that most commonly, Ministries of Education, Research and/or Innovation take decisions on national scientific and thematic priorities for higher education institutions (HEIs) and public research institutions (PRIs).

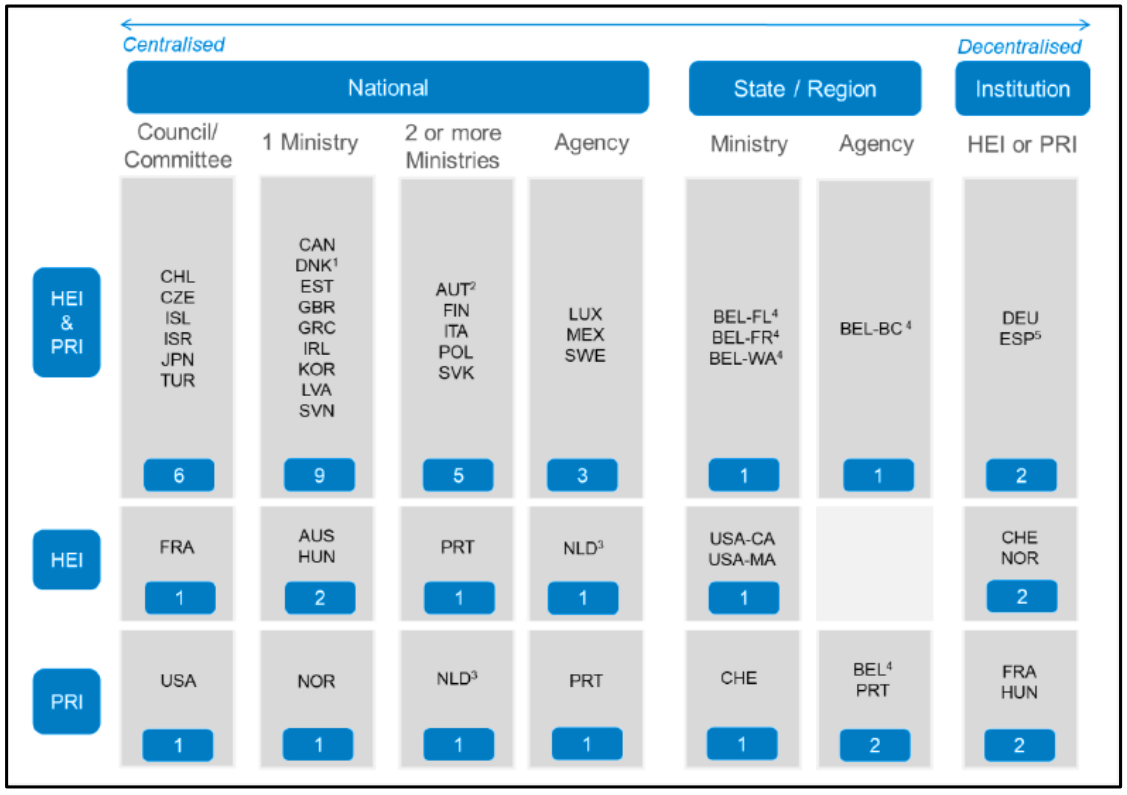

Figure 5.1: Ministries in charge of scientific priorities of HET and PRIs[246]

[245] OECD. 2018. How is research policy across the OECD organised? *OECD S&T&I Policy Papers* No 55, Paris.
[246] Ibid.

On the left side of the figure are countries that use centralised approaches, and on the right side countries that use decentralised approaches. In the instances of 11 countries (of 34, or 32%), there is a single ministry that decides on research and innovation agendas for HEIs, while more than one ministry decides research and innovation agendas in the instances of six countries (of 34 or 18%). In the instances of 11 countries (of 34, or 32%), agencies that are public entities outside of ministries are in charge of setting policy priorities and are responsible for policy implementation regarding public research, or research and innovation councils.

As far as funding is concerned, in most OECD countries ministries provide institutional block funding (32 of 35 for HEIs, 27 of 34 for PRIs). Similarly, national agencies decide on allocations of project-based funding for HEIs in 31 (or 89%) of 35 OECD countries. In countries with funding agencies (31 countries), 19 countries have more than one agency while 12 countries have a single agency. A number of OECD countries have recently reduced the number of funding agencies in order to increase efficiencies and to reduce fragmentation.

Councils are widely established with mandates that include priority setting, policy advice and policy coordination regarding HEIs and PRIs, and are in place in 31 of 35 (89%) OECD countries. A number of countries – i.e. Ireland, Italy, New Zealand and Norway - do not have research and innovation coordinating councils but use other forms of horizontal coordination. In the case of Norway for example, eight temporary sectoral strategy committees for STI called “21 Forums” were created.

Inter-agency programming, i.e. formal arrangements between agencies that result in joint action, is a new policy instruments used to coordinate policy action at the level of implementing agencies. Under such initiatives the funding agencies fund research projects that have to be submitted by university-industry consortia.

Performance contracts and indicators are widely used by the OECD countries to steer/direct research to areas of priority and to achieve pre-established objectives. Among the countries that provide the OECD with information on targets, 12 countries and two regions (Scotland in the United Kingdom and the German state of North-Rhine Westphalia) include education and research performance indicators such as target numbers for Master’s and PhD degrees to be awarded, the share of graduates employed one year after graduation and the number of scientific publications in international journals.

In addition, 10 countries and two regions (Scotland in the United Kingdom and the German state of North-Rhine Westphalia) place emphasis on HEIs’ role in support of business innovation. Innovation-related indicators include the number of patents filed by researchers and/or the university (Australia, Korea and Luxembourg), revenues from licencing intellectual property and contract research (Australia, Korea, Luxembourg and Scotland in the United Kingdom), industry-funded R&D (Estonia, Finland and North Rhine-Westphalia in Germany), the number of spin-offs of students and researchers (Australia, Denmark, Ireland, Korea, Luxembourg and New Zealand), the number of collaborations with industry (Australia, Denmark and Ireland), and the number of innovation vouchers for particular science-to-business collaborations (Scotland in the United Kingdom).

While contexts, challenges and opportunities differ across continents, regions and countries, there are many important observations to be made from this analysis. OECD countries do value their STIs to the extent that they regularly review the appropriateness of the architectures of their systems inclusive of the effectiveness of coordination, collaboration and efficiency. Even the United States, in the face of growing global competition from emerging technological powers, is now considering a landscape transformation that will see it renaming its National Science Foundation by focusing it now also on catalysing innovation.

South Africa equally has to face up to the challenge of the regular review of the appropriateness of its HESTI institutional landscape, which still is largely one inherited from the pre-1994 dispensation. With this in mind, we move on to the mapping of South Africa's NSI, commencing with describing the system as is.

5.3 The "as is" NSI mapping

5.3.1 Mapping the NSI as a whole

In the broader terms of the definition of the NSI, we can consider constituent institutions as those that are actively influencing innovation development with the following characteristics:

- Institutions that generate knowledge by R&D (such as research councils and universities);
- Institutions that actively use science, engineering and technology services for the generation of new value (such as in engineering firms);
- Institutions that rely on highly skilled STI personnel for providing services in their respective disciplines (health professionals are an example); and
- Institutions that help create new ventures by commercialisation of innovative products and services.

Institutions that passively use technology in the form of consuming the value of technology are not considered as a part of the NSI. Typically, these institutions only consume innovation products to streamline and increase value for their offerings. Examples of such would be banks that adopt innovation to improve their business offerings.

Government departments were used as a starting point to collect a list of institutions in the science and innovation landscape (see Figure 5.2 below). This was undertaken by reviewing and analysing various government departmental and agencies reports, including annual reports for institutions it receives funds from or to whom they pay for services provided. This makes government a useful point of departure for mapping out the science and innovation institutional landscape. In addition, the Top 40 JSE listed companies relevant to STI (as per the qualifying characteristics listed above and based on the materiality of the company's headcount, revenue and STI-related R&D).

The NSI organogram can be regarded as comprising three levels of a pyramid:

- At the top, there are the organisations that develop the broad strategy and set policy and procedures;

- The second layer comprise specialised and relatively autonomous agencies that are responsible for directing all activities of a group of R&D facilities; and

- The base of the structure is populated by the individual laboratories and institutes that are mostly the performers of science and technology.

The outcome is a functional depiction of the current NSI, as follows:

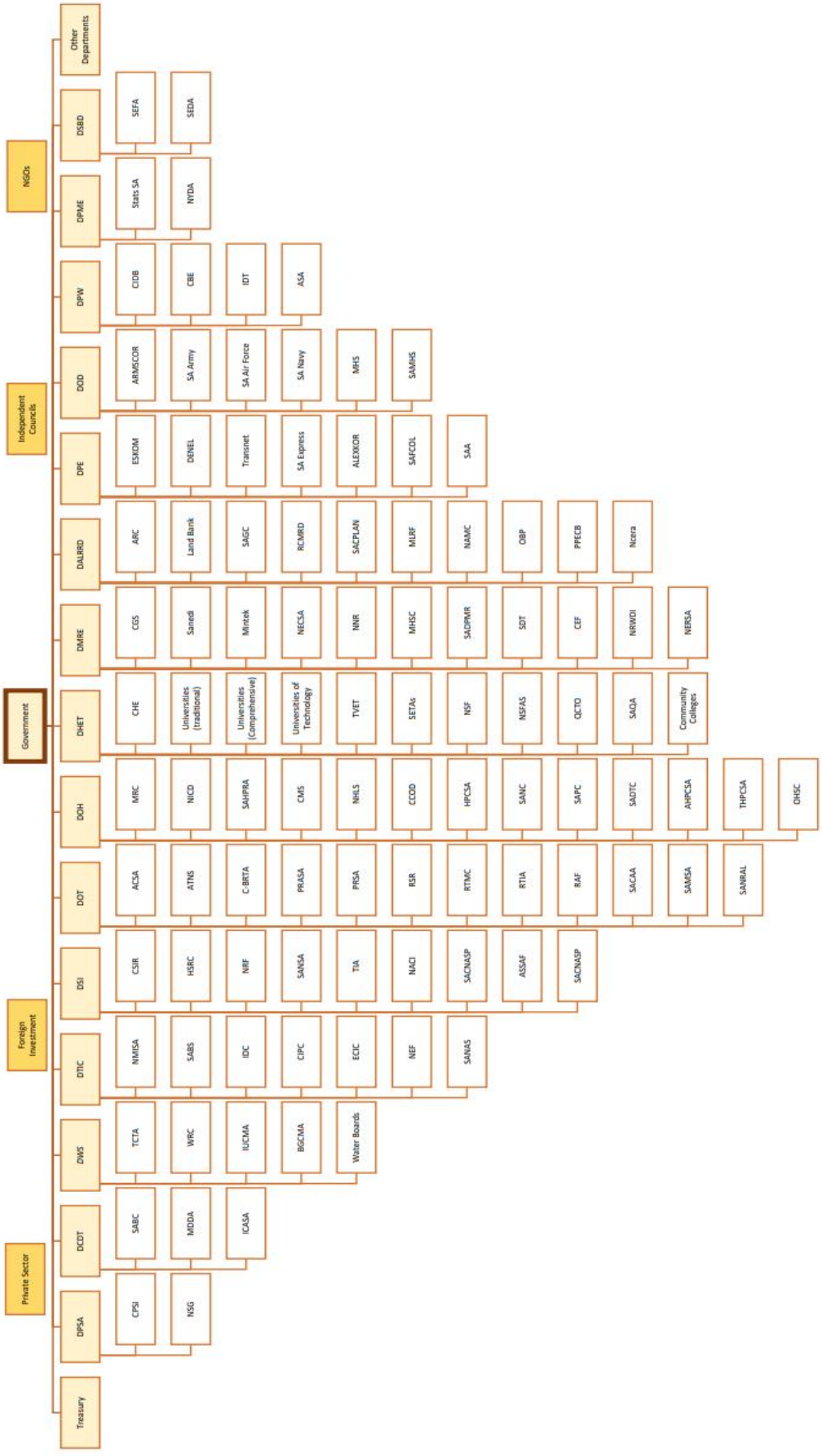

Figure 5.2: The "as is" NSI organogram

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The above NSI mapping is largely based on the reporting arrangements as it follows closely formal administrative mandates and there are functional dynamics that may not be evident from the above mapping. Other logical principles are necessary to depict these other system properties.

Figure 5.3 below is an organogram that focuses mainly on the organisations that are funding and performing research. The organogram appears more manageable, however there are now scientific organisations (e.g. SAWS) that appear under other government departments.

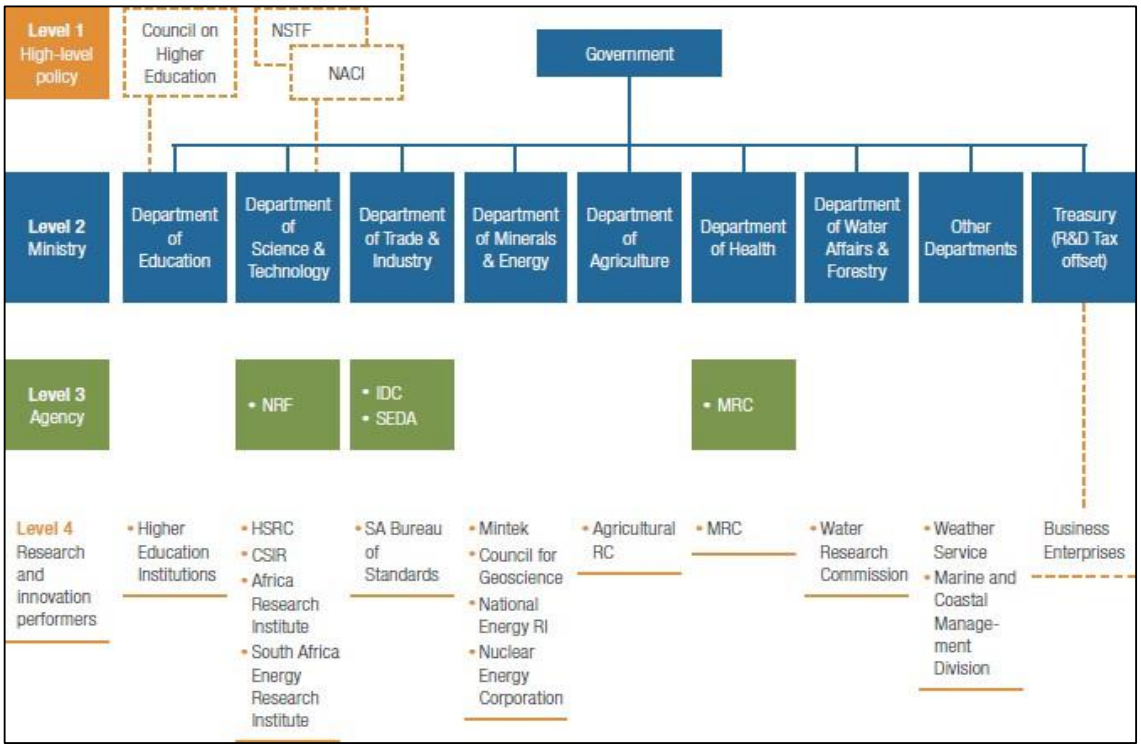

Figure 5.3: NSI organogram R&D funders and performers

In the interest of revealing various facets and attributes of the system, the Review Panel developed a set of interconnected organograms. Such pictograms are mapped out as consisting of institutions represented by nodes, with the interconnections shown as connecting lines. The interconnections are defined as flow parameters representing either financial details, human resources (capacity) or R&D (publications and IP). The mapping allows visualisation for various depictions of the NSI. Here, the maps are used to map some of the key subsystems within the HESTI institutional landscape.

5.3.2 Network mapping of key subsystems of the HESTIIL

In Chapter 6, four transdisciplinary Grand Challenges or Missions are proposed to activate a catalytic effect on the HESTIIL that the Review Panel believes will help to pivot the system towards innovation outputs with more pronounced social and economic returns. These four missions are:

- *Health and Well-Being* - which would allow us to put in place proactive efforts to deal with all communicable diseases that affect our communities, improve life expectancy and achieve food sovereignty and nutritional democracy.
- *Climate Crisis/Change* – sustaining the integrity and enhancement of our ecosystem services and their relation to an improved quality of life.

- *Work, Livelihoods in a Changing Technological World* – responses that redress vital gender, race, class, generational, income and household inequalities; and
- *Learning, Education and Scholarship for a Future Society* – to enhance the proactive scientific, technological and interpretative capacities in the system.

In this part of the report, we use the above four RDI areas to generate deeper insights into how institutions and organisations work together with the HESTIIL. For this purpose, network maps are developed for each area to demonstrate the nature of institutional relationships and scale of resource flows involved. First, we describe how the diagrams are generated and should be interpreted.

5.3.2.1 How to read the network diagrams layout

The network diagrams used in this report are commonly in use in bioinformatics, where complex and detailed molecular interactions are studied to learn the behaviour of organisms. Typically, network analysis is used to represent biological molecules with physical properties, genetic and functional interactions. The visual networks are preferable to Excel tables in discovering relationships in large data sets. This work leaves room for big data analytics to be used in future to extract more useful information on the behaviour of the NSI. *Cystoscape*, an open source software used in bioinformatics, was used to generate the network diagrams.

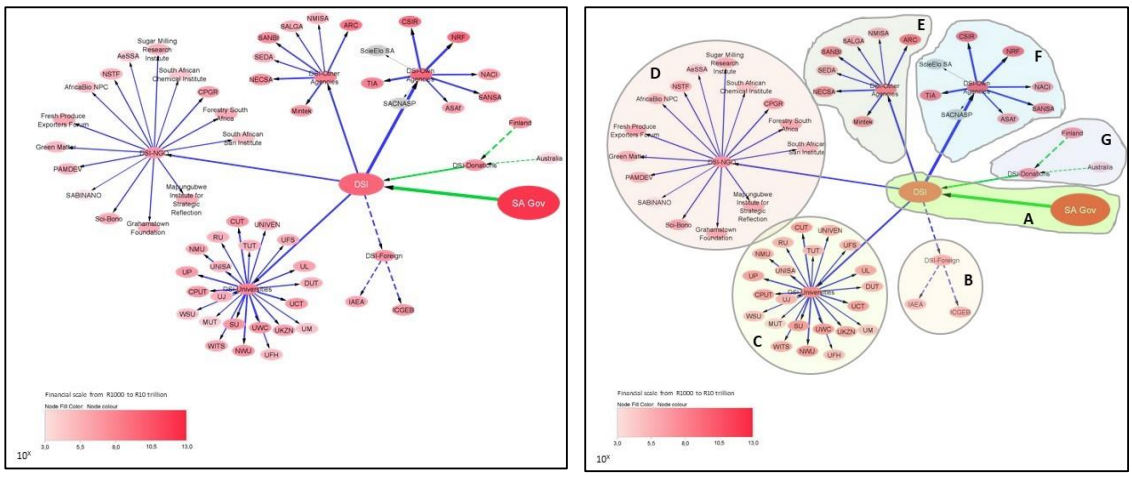

Figure 5.4: Illustration of network diagrams

The network shown on the left is a simplified depiction of institutional elements for the DSI. This will be used as an example to "walk" the reader through how to interpret these sketches. On the right the same network is then shown with demarcations of common network linkages applied through all the network diagrams that will be discussed later in the report.

Firstly, the nodes represent institutions or proxies of intuitional categories. The largest node size is assigned to a central entity in the landscape (designated A in the figure on the right), in all cases that would be the government, which constitutes the hub of the topography. The second largest node size is used to depict other key departments that play an active role in an RDI area. In this discussion, the maps will describe the RDI networks of four transdisciplinary areas that are important for the country's development, which are referred to as the Grand Challenges or Missions. The third node size is used to depict all other role-players. The proxy nodes are used to describe defined categories used to organise connecting points to other institutions. These proxy nodes are used consistently in the topographic diagrams to represent the following:

- Foreign payment transfers, which would cover items such as registration for international memberships (Demarcation B, in the previous figure)
- Payment transfers to universities (Demarcation C, in the previous figure)
- Payment transfers to NGOs (Demarcation D, in the previous figure)
- Payment transfers to departmental agencies (Demarcation E, in the previous figure)
- Payment transfers to other departmental agencies (Demarcation F, in the previous figure)
- Payment receipts for donations or foreign payments (Demarcation G, in the previous figure)

The nodes are in colour to represent the amount of money vested in the various institutions involved. A single hue is used with varying saturation to indicate the level of financial investment. The proxy nodes are representative of the total inlet and outlet links connecting to them. A heat map is then shown for all the nodes involved in the network. The legend at the bottom of the diagram indicates that the heat map shows the order of financial magnitude plotted as a logarithmic function (log with a base of 10). This is useful considering that the idea is not to show the heat map with exact amounts involved in the institutions. Rather, a quick depiction of the order of magnitude of financial flows involved in the interconnections is helpful when presented with large data sets in the form of interconnecting institutional nodes.

The interconnecting lines all have arrow heads indicating the direction of financial flow (usually institutional transfer to the entity being pointed to). In some cases, the lines may have the transactional financial value as a label on the line. The blue colour in the interconnecting line is used to indicate transfers within the institutional landscape representing the NSI. The green colour is used to indicate funds that come into the institutional landscape. This is represented by the government appropriation through departments, donations or funding from local or international agencies and private companies. Dotted lines are used to indicate transfer of funds involving foreign institutions.

The figure below shows the characteristic curve used to determine the line thickness. Ideally a straight line would have worked however subdividing the linear line into three different linear lines with slightly differing gradients works better for the visual depictions of the different financial flow lines.

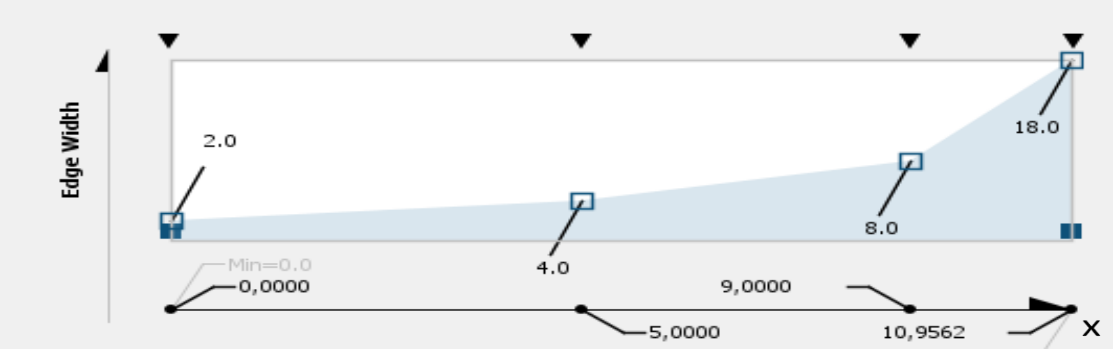

Figure 5.5: A depiction of a map line

The financial flow represented in the thickness of the lines is represented as a logarithmic scale by the values on the x-axis of the above diagram. From the previous figure we can see the following flows for the simplified network diagram:

1. Government appropriation for about R8 billion going to the DSI (Demarcation A);
2. Donations from Finland and Australia (Demarcation G);
3. DSI payment transfers to international agencies (Demarcation B); the payment is relatively small hence reflected by thinner lines and lighter colour saturation for the connecting nodes;
4. DSI payment transfers to various universities (Demarcation C);

5. DSI payment transfers to various NGOs (Demarcation D);
6. DSI payment transfers to various local agencies such as science councils and DFIs belong to other departments (Demarcation E);
7. DSI payment transfers to its own reporting entities or agencies (Demarcation F). This accounts for the largest transfers made by the department, hence thicker lines and darker saturation for nodes. Two nodes, SACNASP and ScieElo SA, are greyed out because they are known interconnecting institutions, but for the year 2018–2019 there was no financial transfer towards them.

5.3.2.2 Layout of the sketch

The network diagram consists of nodes connected with interconnecting lines that are arranged in a layout. There are various layouts used to help arrange the nodes and their interconnecting lines. The adopted layout for the networks studied in this report is best explained with a metaphor that sees nodes as same-charged magnets, connected with elastic strings of similar original unstretched lengths. Therefore, nodes repel from one another while links pull the nodes together. Such a layout allows one to see clusters grouping easily, something that is useful for visual analysis that can describe the interconnectedness of the network. The various aspects that can be read in analysing the sketch are tackled in the next section.

5.3.2.3 Analytical characteristics

Visual analysis can be done by one of the approaches listed below:

- Clustering – identifying a subgroup of connected institutions sharing a connection attribute. Usually the cluster would all be sharing the same connection.
- Materiality of connection – connection with high flow parameters show their significance as a part of the network.
- Diverse connections – the diversity of connection is a strong indicator of the interconnectedness of an institutional node to the rest of the network.
- Analysing the interconnection type:
    - Direct linkages of departments (such as redirected funds and inter-ministerial engagement) are omitted in the network. There is known direct funding among departments, and it is expected that this would be overseen by a ministerial steering committee with its own clustering of departments for specific goals.
    - Linkages with other agencies are a primary indicator of how departments connect effectively within the NSI network. A well-interconnected department would typically find interest in funding or obtaining service from other agencies within the NSI.
    - Linkages with NGOs and the private sector through payment for services, memberships subscriptions and financial sponsorships is a good measure of interconnection with non-government bodies within the NSI.
    - Local and foreign funding towards the NSI shows an interest in local innovation which comes with extra funding especially towards R&D. The ability to attract such funding outside of government is important.
- Nodal heat maps showing intensity of financial activities.
- Passive and active linkages – passive linkages simply show a known connection that does not have a financial flow. Sometimes infrequent financial transactions are made, resulting in passive linkages. Part of the analysis over time can yield ineffective passive links.
- In general, part of the analysis is to look for patterns from which useful information can be deduced.
- Densely connected nodes suggest a strongly interconnected network.

- Using ratios to benchmark performance (will be possible later, and is not in the scope of this report)
- Finding hubs, or central nodes, can suggest the need for creation of institutions around the hubs as a way of scaling up.

In the case of analysis for historic data within the institutions, time analyses can be made. Some of the suggested analyses would be as follows:

- Recurring transactions showing permanency of institutions, less recurrence could mean a need to review the linkage for its relevance. Some linkages' occurrence is infrequent but highly material, thus important.
- Trendline of financial transactions.

The above is applied to depict the network maps of the proposed missions in the discussion below. Each map will be followed by a brief discussion of pertinent observations.

I. Health and well-being

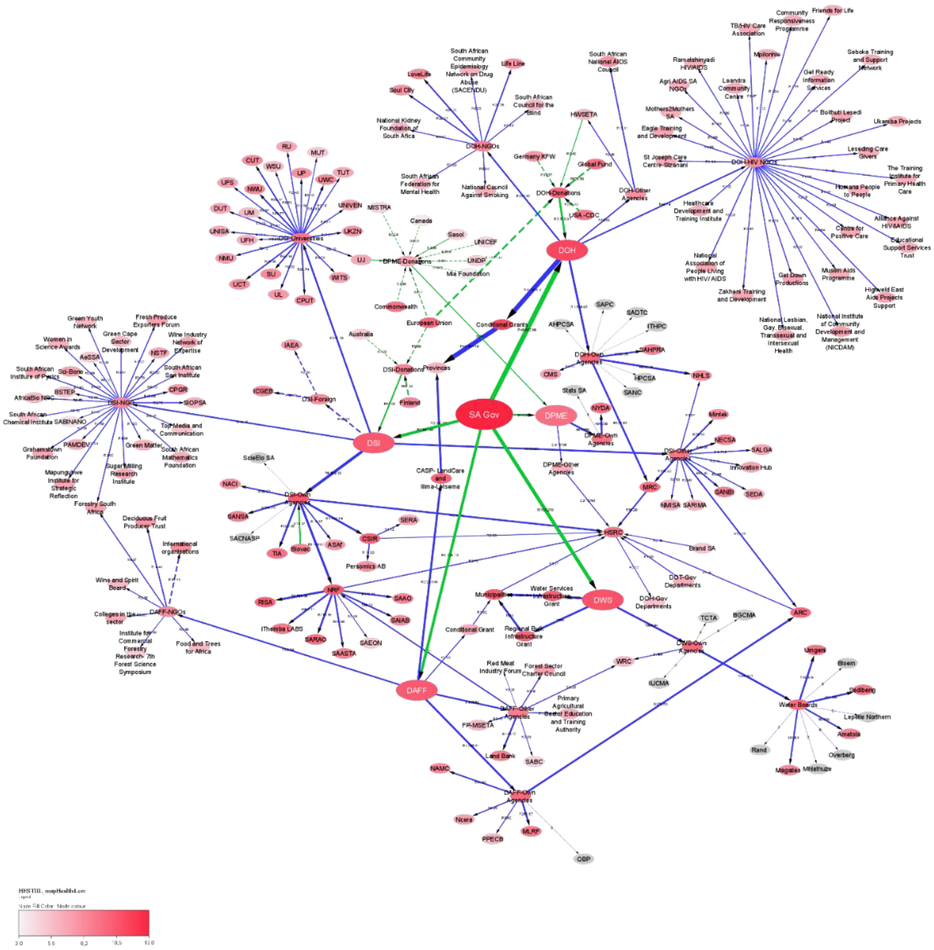

Figure 5.6: Health and well-being network map

The map shows that DSI generally connects well with many institutions within the NSI, albeit with room for improvement. The department attracts reasonable funds from foreign entities, with the European Union being a key partner. This is important when considering the nexus between government and universities in stimulating innovation in the health sector. This interconnection is essential to address

the challenges in the health sector. The interconnections with universities are through the academic hospitals, where general training of doctors and other health practitioners is performed.

Through the NHLS and MRC the DSI performs an active role in shaping the research agenda for health sciences. The DSI contribution of about R138 million is substantial when compared to the R625 million from DoH. There are many other interconnections that illustrate the various partnerships in this sector. Many more insights could be drawn from these relationships to inform better support for RDI in health and well-being.

II. Climate change

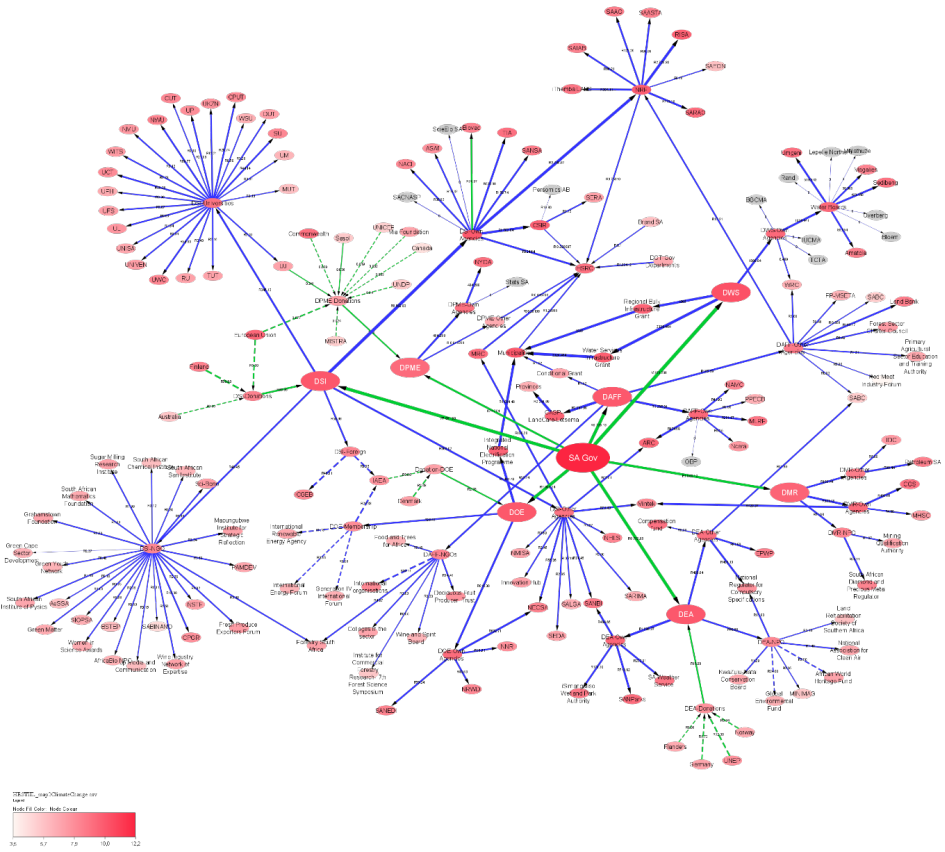

Figure 5.7: Network map for climate change

The same observations as in Health and Well-being regarding the role of DPME apply to Climate Change. The DSI generally connects well with many institutions and supports other departments and agencies in the work on climate change. The CSIR collaborates with DEFF and SANBI to conduct strategic environmental assessments and have contributed to the rollout of wind and solar energy, which resulted in the identification of eight renewable energy development zones and five power corridors. The DEFF attracts significant foreign funds from various entities in Europe and elsewhere; this however comes second to the amounts raised by the DSI. The NGOs are active in environmental programmes and manage to attract significant funding as well.

Some of the big challenges in this area include environmental degradation, loss of biodiversity, droughts and desertification, and various forms of pollution. These challenges will only be addressed when all institutions work collaboratively in developing technologies and other solutions. The DEFF, through its

agencies, is a critical role player in building cooperation in the country. DMR seems to have no formal financial linkages with other local agencies and NGOs. The department interacts more with international bodies around different energy technologies. Much of its transferred R4 billion goes to conditional grants for the Integrated National Electrification Programme. NECSA, NRWEDI and NNR receive a combined budget of more than R740m. SANEDI is the only non-nuclear-focused entity of the DMR.

5.4 NSI description based on scientometrics

The next step in the description of the HESTI institutional landscape involves what is referred to as scientometrics. This is a scientific field by which the state of science and technology can be observed through the overall production of scientific literature and patents at a given level of specialisation. Time series trends as well as comparisons with other countries have the potential to reveal the state of science and technology in a country.

For our purposes we use publications, patents and PhD graduations in order to construct a coherent view.

5.4.1 Bibliometrics

The Figure 5.9 below shows articles according to co-authorship character. Articles with multiple institutions are counts of articles with two or more institutional addresses. Articles with domestic institutions only are counts of articles with one or more institutional addresses all within a single region, country, or economy, which include single author articles and articles co-authored under the same institutional address. Articles with international institutions are counts of articles with institutional addresses from more than one region, country or economy.

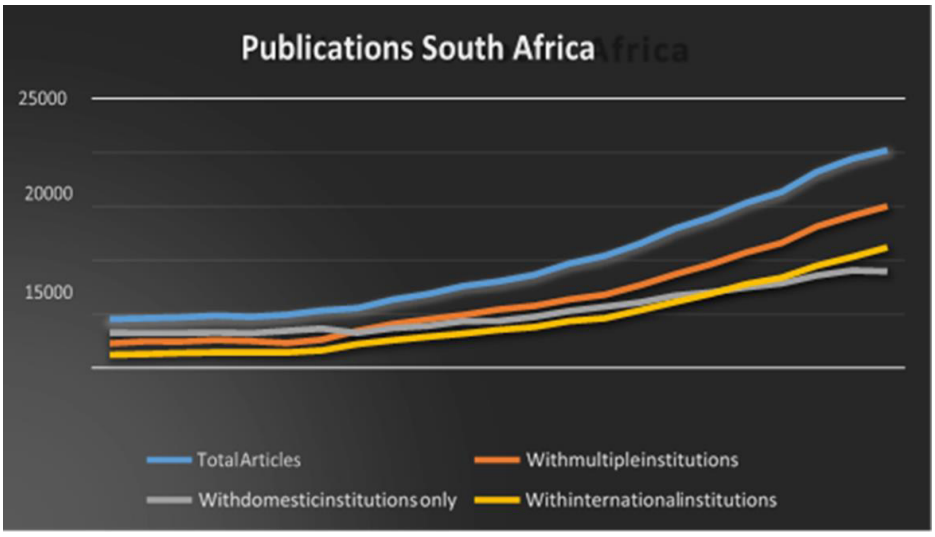

Figure 5.9: SA publications according to co-authored mode

The total articles show that during 1996 South African authors published 4 540 publications and during 2018 the country produced 20 203 publications. That represents an increase of 345% over the period.

The number of publications with “domestic institutions only” was 3 251 at the beginning of the period, and 8 951 at the end of the period, representing an increase of 175%.

The number of publications with international institutions (international collaborations) was 1 252 at the beginning of the period and 11 188 at the end of the period – an increase of 790%.

The phenomenal growth in the publications output shown above can be linked to some critical events in the policy landscape, not the least of which was the new funding formula as can be postulated from Figure 5.10.

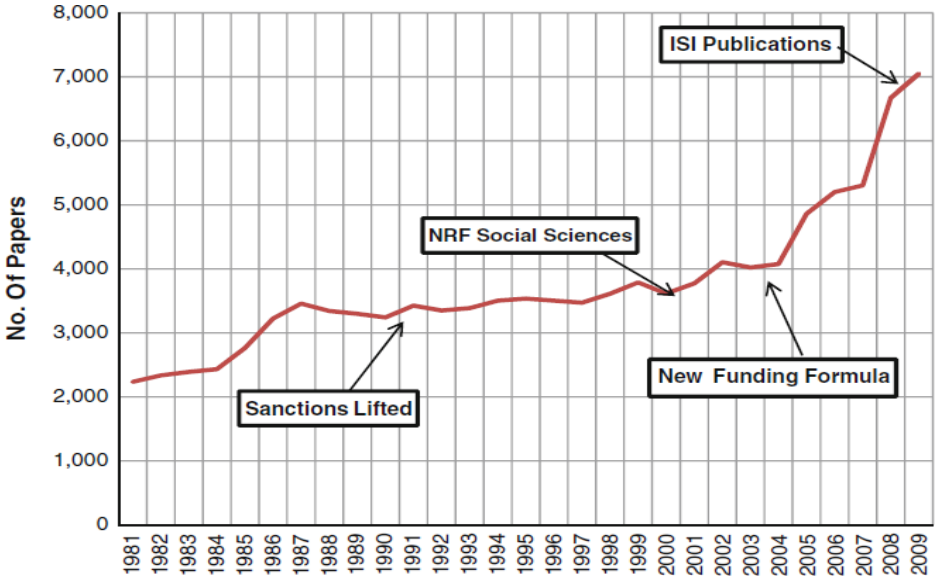

Figure 5.10: SA publications and critical events[247]

5.4.2 Patents

The United States Patent and Trademark Office (USPTO) grants several different types of patents, of which utility patents or patents for invention are the most important. South Africa recorded a modest growth in registrations in the past decade as shown below.

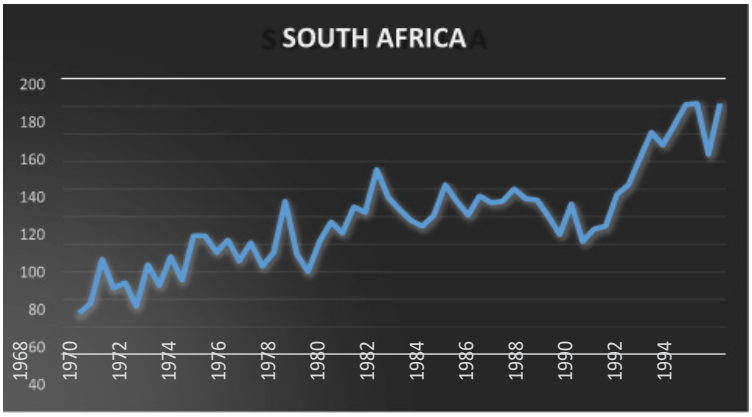

Figure 5.11: Patents granted to South African inventors by USPTO[248]

However, the more intriguing aspect of patents registration has to do with the local registering organisation. In South Africa, the authority granting patents is the Companies and Intellectual Property Commission (CIPC). Unlike the USPTO, CIPC is a non-examining authority that registers patents. This

[247] Source: Pouris, 2012.
[248] Source: USPTO Database.

means that patents may be of dubious quality and value and even so, the CIPC will register these. Worryingly, such an approach may attract international companies that simply seek to stifle the innovation initiatives of local firms, in particular those operating in the technological domains.

	2008	2009	2010	2011	2012	2013	2014	FOREIGN
	%							
Civil engineering	39	38.1	34.2	31.9	34.9	29.6	29.5	**70.5**
Mechanical elements	26	24.8	27.8	18.5	31.2	18.6	28.7	**71.3**
Basic communication processes	9.1	18.8	50	0	18.2	0	25	**75**
Transport	30.7	23.5	23.1	23.9	22.3	23.1	23.7	**76.3**
Control	25.7	26.4	26.6	23.8	21.5	29.8	19	**81**
Other special machines	19.1	12.5	20.6	12.3	13.4	14.6	19	**81**
Textile and paper machines	8.3	5.3	8.9	6.9	5.4	6.6	4	**96**
Food chemistry	7.4	4.3	3.6	5.3	7	6.1	3.1	**96.9**
Basic materials chemistry	8.1	4.6	5	4.8	3.9	3.8	2.5	**97.5**
Pharmaceuticals	1.3	1.3	1.2	2	2.6	1.7	1.4	**98.6**
Surface technology, coating	6.5	8.5	7.3	0	6.1	5.8	1.4	**98.6**
Macromolecular chemistry, polymers	2.7	2.2	7.8	0	1.5	4.7	1.3	**98.7**
Biotechnology	1.4	3.8	4.4	3.3	4	2.3	0.9	**99.1**
Organic fine chemistry	0.5	1	0.6	1.3	1.8	3.5	0.6	**99.4**
Micro-structural and nanotechnology	0	50	0	N/A	0	0	0	**100**
Unknown	16.7	15.8	15.8	11.9	14.9	21.8	22.9	**77.1**
Analysis of biological materials	12.5	0	0	N/A	N/A	N/A	N/A	**N/A**

Table 7.1: Percentage share of resident and foreign patent grants by technology[249]

Table 7.1 above shows that most patents granted by the CIPC were to foreigners (averaging above 70%). It is intriguing that foreigners are so interested in protecting their intellectual property in South Africa. Strikingly, pharmaceuticals and biotechnology foreign-owned firms own more than 98% of the granted patents.

It can be argued that the CIPC's current mode of operation constitutes an obstacle within the country's innovation landscape which will have long-term consequences. Given the significance of this finding, the Review Panel is of the view that the CIPC should, until a new system is put in place, with immediate effect cease the issuing of patents. An alternative that can be used in the interim is for the CIPC to examine applications through foreign patent offices. In such an arrangement, applications that are examined by international authorities under agreement with the CIPC will be granted by the CIPC. The is an approach that is used by many other countries.

5.5 Issues and findings

The most significant issues and findings that arise from our review and analysis of the institutional landscape mapping, scientometric assessment, case studies, international reviews and stakeholder opinions and advice are as follows:

1. There is no coherent system of reporting across science entities, universities and SOEs. This makes it impossible to track and monitor live system-level information.

[249] Source: WIPO IP Statistics Data Centre.

2. The R&D outputs of the system have resulted in sub-optimal social and economic impact.

3. The NSI is poorly interconnected and siloed; and instead of collaborating, actors are overly competitive.

4. There is no coherent system-level agenda, priority setting and steering; and there is no coherent system monitoring.

5. It is evident from our study of Asia's newly industrialised and industrialising countries that in order to industrialise and create multinational export firms, the state should lead the process of industrial development by developing a national innovation strategic intent. This is typically achieved through the National Science and Technology Councils (NSTC) established at cabinet level. NSTCs formulate and coordinate science and technology policy. Notably, Japan's CSTI takes a bird's-eye view of Japan's entire science and technology landscape and facilitates and coordinates the Cross-ministerial Strategic Innovation Promotion Programme (SIP) that cuts across the siloed working of government departments. CSTI's cabinet influence enables the redirection of funds from all ministries. It also influences government procurement policies to address critical STI needs that offer a competitive advantage to the Japanese industry and economy through innovation.

6. The system-level advisory mechanism, NACI, is significantly suboptimal in terms of its membership, capacity, authority and influence, and its advisory role is limited to the entities within the DSI portfolio.

7. There is little to no coordination and integration of strategy and planning between DSI and DHET, the government departments that sit astride basic and applied research, and innovation and technology transfer. These departments work in isolation.

8. Science councils and entities were created by their founding government departments to serve their departments and relevant communities. However, it is apparent that over time the relationship between some of these government departments and science councils and entities has weakened and in certain cases there is no evident relationship.

9. Business and industry's role, participation and investments in domestic research, innovation, technology transfer and industrialisation are in long-run decline and effectively off-shored to science entities and universities in industrialised nations. This development has devastating consequences for domestic reindustrialisation and the development of new industries.

10. Tax incentives to catalyse and stimulate research, innovation and technology transfer are popular instruments internationally. Appropriately designed tax incentives can increase private research spending by at least an amount equal to the loss in tax revenue. Furthermore, the social returns on such research, innovation and technology transfer far outweigh private returns. Presently, South Africa offers a 150% research and development tax incentive to qualifying companies. During 2016 the Minister of Science and Technology, in an effort to strengthen partnerships between government and the private sector on matters related to research, development and innovation, established a joint government-industry task team to make recommendations related to the research and development (R&D) tax incentive. The task team found that South Africa's tax incentive system was among the lowest in the world in terms of tax deductions. The highest combined (additional and super) deduction is offered by Singapore at 400%. The average combined research and development tax deduction across about 16 countries is close to 220%.

11. Venture capital is a specific type of finance available to finance and catalyse start-ups, and access to this finance is a crucial element in the innovation cycle. Venture capital enables translating the results of research and development into commercial outcomes. South Africa has an active venture capital environment. However, government has an opportunity to set in place initiatives to encourage new high-technology start-ups, including risk-bearing tax regimes, royalty-linked loan schemes, information and counselling services and support for 'business angel' networks. Moreover, the section 12J incentive appears to have been effective and efficient (12J Industry Association) and the Committee recommends its extension after 2021.

12. All social and economic sectors require fast internet coverage. Moreover, 4IR and other innovation-driven solutions in all social and economic sectors depend on a viable fast internet infrastructure.

13. There is no 'through the NSI value-chain' project/programme conceptualisation, implementation and line-of-sight. As a result, the NSI has very few top-of-mind successes compared to leading countries in innovation. There is a need for improved learning from past mistakes as we show in the case studies reviewed in this report.

14. The profile and output of postgraduates and research publications with social and economic impact in Engineering and its allied disciplines and knowledge fields, notably information, computer and software studies and advanced digital technologies, are low when compared with leading peers.

15. TIA is short on leadership stature and financial capacity and is consequently unable to pursue the ambitious goal of facilitating and commercialising hundreds of new ventures in advanced technologies.

16. A set of NSI institutions are either too small, have little impact, are poorly funded or their location within the NSI is misplaced.

17. Linkages between individual institutional mandates and annual performance plans on the one hand, and between these and their roles and contributions to the NSI on the other hand, are weak to non-existent.

18. The issuing of unexamined patents to foreign firms by the CIPC constitutes an obstacle to the full development of the country's innovation system. This also creates intellectual property development obstacles for local firms. These obstacles will be around for 20 years in each case (the life expectance of a patent).

19. The complementarity between acquiring foreign technology (import and licensing) and domestic technological improvements of the acquired foreign technology is the key element in the technological change strategy that has enabled the Asian countries to catch up to industrialised countries.

20. Foreign Direct investment (FDI) has various economic benefits for the host country – ranging from availability of capital, facilitation of transfer of technology as in the case of China through joint ventures between the state and the multinational firms, and the development of domestic industrial infrastructure. Poorly coordinated FDI can stifle the innovation system as in the case of Brazil as multinational firms offshore and invest in research and development in their host country.

Case study on capabilities for innovation: COMRO

The Chamber of Mines Research Organisation (COSMO) demonstrates some of the best of South Africa in disruptive innovation. However, the potential commercial opportunities were scuppered by the lack of complementary capabilities necessary for success in innovation.

CASE STUDY 6: LOST OPPORTUNITIES IN THE MINING TRANSITION

Despite the depth of its gold deposits, in the late 1960s, South Africa remained one of the world's principal gold producers. Mining's legacy of internalised racism and the broader political economy of racial discrimination precipitated the international isolation of the South African mining finance houses. These factors would eventually lead to the common cause that supported the generation of social capital and collaboration in the mining industry.

As a consequence of the depth of gold deposits, South Africa's gold mining companies cooperatively established the Chamber of Mines Research Organisation (COMRO) to undertake research and development (R&D) of alternative technologies to extract the gold-bearing host rock. COMRO had a systematic coordination throughout the innovation funnel as it interacted directly with the spectrum of R&D parties and national and international equipment manufacturers in facilitating the emergence and commercial supply of important alternative technologies. This resulted in the development, within the space of 26 years, of commercially successful complex hydraulic technologies enabled through a cost-effective, low-risk model.

The changes in the political economy in the 1990s, which would stimulate the internationalisation of the previously isolated mining finance groups, and the mergers and acquisitions in the international mining sector, would lead to the end of the cooperative R&D. This would in turn lead to the demise of the successes that COMRO had gained locally and internationally.

Strategic intent: To undertake R&D of alternative technologies to extract the gold-bearing host rock through the mechanisation research programme.

Linkages: COMRO collaborated with local equipment suppliers, equipment manufacturers and other public research institutes, including South African universities, for R&D at the various developmental phases. It conducted basic research and early technical trials, maintaining a critical stock of knowledge internally to ensure continuity of development. The organisation also collaborated with overseas-based companies in developing some of the mining equipment.

Research and development: A ten-year research mechanisation programme was initiated to improve on the efficiency of underground gold-mining operations. This programme consisted of two distinct groups of technologies: conventional and revolutionary. The conventional technologies focused on improving existing mining methods with a focus on hydraulic drill equipment with better efficiency, while the revolutionary technologies focused on changing mining methods with a focus on hydro-hydraulic or 100% water technologies. The establishment of this programme notably in the early development of the hydraulic drill, enabled South Africa to participate in an international learning environment through their collaboration with internationally based firms from countries like the UK and Germany. The collaboration of COMRO with a broader base of local and international participants such as suppliers, local manufacturers and public research institutes was to ensure the market viability of the developed technologies, to incorporate manufacturing know-how into product development, as well as to foster a viable mining equipment manufacturing industry to supply the local and export markets.

Absorptive capacity: The limited absorptive capacity of local manufacturers led to COMRO's collaboration with international manufacturing enterprises. The international collaboration facilitated technical skills transfer. In this regard, COMRO was deliberate in involving South African universities in the programme to ensure that they develop and sustain tertiary capabilities that would support the revolutionary technologies being developed.

Foreign direct investment: The development of these revolutionary technologies attracted multinational enterprises to invest in South Africa and to participate in the R&D activities. An interesting collaborative structure between various multinational enterprises (MNEs) and COMRO emerged in the development of the mining technologies, and South Africa became one of the international leaders in mining hydraulic technologies. Contrary to the notion that MNEs invest in research activities in the home country, COMRO's research became attractive to its competitors, that is, the MNEs that supplied the competitive mining equipment comparable to that which COMRO was developing.

Technology acquisition: Partnerships were developed with international companies that had extensive in-house research to achieve international technology transfer and mutual development of novel technologies. The British National Coal Board provided the foundation knowledge that South Africa leveraged and accelerated catch-up to reach the international forefront of hydro-hydraulic technologies. Some components of the technologies were adopted from development of other complementary technologies from the international market. It is not clear whether these technologies were licensed.

Challenges: Technical challenges faced in the development of commercially viable hydraulic drilling systems presented a learning opportunity and diversified the research for COMRO as they led to the development of complementary technologies through their strategic collaborations with multinationals. Such strategic collaborations also enabled COMRO to adopt advanced global technologies and repurpose these for the development of their own technologies.

Output: Market-ready products: First in the market with 'green' hydro-hydraulic mining drill that is production efficient with health and environmental savings; and, indigenous tech-based firms: The COMRO initiative stimulated the emergence of indigenous firms in the mining equipment sector in the 1980s that are still in existence.

Commercialisation:

- There are currently only four mines in the world that are using the revolutionary mining equipment developed in collaboration with COMRO.
- The limited diffusion of the technology is due to the complexity of the development process, which increases manufacturing costs. Furthermore, the knowledge intensity of the technologies can be a barrier to adoption and different maintenance practices need to be adopted by end users.
- The nature of mining equipment being geographic specific in their design creates a barrier in the mass adoption of the technology.
- There are other commercial application opportunities for the revolutionary technology in sectors beyond mining that had not been fully explored by COMRO before it was dissolved. Rising interest in the circular economy as well as the broad potential application of the hydro-hydraulic drill presents an opportunity to revisit the diffusion of the product beyond its primary market, as one would assume that SA still has the tacit knowledge of its development.

Chapter 6

Key issues and findings

6. Key issues and findings

At the end of each component of this HESTIIL Review, i.e., the Situational Analysis, Institutional Capacity Analysis, and the Landscape Mapping, we presented a comprehensive discussion of the key issues and findings. In this Chapter, in preparation for the next section on Recommendations, we present a compendium of the key issues and findings gathered across all the components of the review. Furthermore, we lay out the implications of the insights gathered from these findings.

6.1 Summary of issues and findings

The overriding finding of the Review Panel is that the HESTI institutional landscape is not adequately capacitated to support the achievement of the country's objectives as outlined in the NDP. As a consequence of the gaps and shortcomings of the HESTIIL, the capacity of the NSI to drive knowledge-based economic growth (and *ipso facto* inclusive social development and shared prosperity) through to industrial development is severely constrained. The Review Panel is of the view that unless urgent and decisive action is taken, there is a real danger that the gains that have been made since 1994 in developing the country's NSI could slide into regression, leading to incalculable social and economic costs to the people of South Africa.

The following is a summary of the key issues and findings that emerged from this HESTIIL Review:

1. Although official documents – from the Constitution[250] to the NDP and other NSI organisational policies and plans – are replete with references to values, they are generally eschewed in implementation plans and management practice. Performance plans, annual reports, human resource management and development protocols, in general, all miss out on the opportunity to leverage the country's sound value system for people and organisational development.

2. With a few notable exceptions, the NSI is poorly interconnected and chronically siloed. This gives rise to incoherent and suboptimal programmes. Instead of cooperation, unhealthy competition is generally rife, particularly within the public sector. Opportunities for developing programmatic synergies are not seized upon as organisations, and units within them, chase after scarce resources. The existing incentive schemes do not adequately promote collaboration and are often implicated in polarising the system. Crucially, the current HESTI policies and incentive schemes have not promoted sufficient private sector participation in local innovation.

3. There is no coherent nor comprehensive system-level agenda and priority setting. There is little coordination and integration of strategy and planning even between DSI and DHET, let alone across the whole of government. As a rule, government departments work in isolation of each other, despite specific provisions in the Constitution that demand cooperation[251]. Furthermore, the lack of an apex oversight authority disables the system from deriving the benefits of an elevated steering mechanism that can foster cooperation within government and across other sectors within the NSI. In order for the country to fully realise the social and economic benefits envisioned in the NDP that should derive from STI, this situation must be remedies, and urgently so.

[250] RSA. 1996. Constitution of the Republic of South Africa, Chapter 3.
[251] RSA. 1996. Constitution of the Republic of South Africa, Chapter 3, Section 41.

4. The apex and system-level advisory mechanism – the National Advisory Council on Innovation (NACI) – is significantly suboptimal in terms of its membership, capacity, authority and influence. Even when it conducts important studies that bear system-wide implications, its advisory role is limited to the entities within the DSI portfolio, thereby significantly confining its desired impact.

5. The role of business and industry in local innovation is waning quite dramatically, and their participation and investments in domestic research, technology transfer and industrialisation are, troublingly, in a long-run state of decline[252]. There are strong indications that investments in these activities are effectively off-shored to science entities and universities in industrialised nations. This trend has devastating consequences for the development of South Africa's NSI, and for reindustrialisation and the creation of new industries.

6. HESTIIL is situated within and is inextricably linked with the country's political economy. The situational analysis revealed that key forces and tendencies that play out and often polarise the South African political economy have direct implications for HESTIIL. These include phenomena such as rent-seeking, an excessive profit motive, adverse interorganisational network behaviours and undesirable financial outflows. These practices – some of which have been adopted by SOEs and other public entities – are inimical to innovation and a people-centric policy regiment. Financial outflows, both legal and illicit, constrain private sector investment in research and development and thus undermine the capacity of the economy to grow.

7. The state-owned enterprises (SOEs) have, troublingly, since the end of apartheid, forfeited their role as key actors within the NSI. Their participation in R&D has fallen precipitously across all key measures. This underscores the diminishing role of this sector in the development of a knowledge economy[253]. The ambitions of the STI White Paper and the forthcoming Decadal Plan for STI are unlikely to be fully realised without a revival of the SOEs as key players in the knowledge enterprise. The extensive geographical and functional footprint of the SOEs in the economy is a necessary asset for extending the participation (and benefits) of the marginalised actors and communities in grassroots science and innovation.

8. The NSI conceptual framework has succeeded in organising policymaking, and the monitoring and evaluation of knowledge-based activity in the country. It has also fallen short in some important respects, notably in accommodating poor and marginalised sections of the population. South Africa has made great strides in human development. These strides are however blemished by the country's high level of inequality[254]. Importantly, the conceptualisation of inclusive innovation in the STI White Paper[255] should be revisited and would benefit from rigorous analysis of the issues that motivate for inclusivity. Such an approach would increase the likelihood of achieving the intended goals and objectives.

9. There is no coherent system of reporting across science entities, universities and SOEs. This makes it impossible to track and monitor system-level information on a real-time basis. Furthermore, the lack of measures to determine social and economic impact in the current

[252] CeSTII. 2019. South African National Survey of Research and Experimental Development: Statistical Report: 2017/18. HSRC: Pretoria.
[253] Statistics SA. 2019. South African National Survey of Research and Experimental Development: Statistical Report 2018/18. Pretoria.
[254] UNDP. 2019. Inequalities in Human Development in the 21st Century: Briefing note for countries on the 2019 Human Development Report – South Africa.
[255] DST. 2019. White Paper on Science, Technology and Innovation. Pretoria.

innovation metrics militates against accurate tracking of progress. Linkages between individual institutional mandates and annual performance plans of many entities on one hand, and their institutional roles and mandates within the NSI on the other, are weak to non-existent.

10. The HESTIIL Review Panel identified several institutional weaknesses both within and between some of the key entities. A set of NSI institutions are either too small, have little impact, are poorly funded or their location within the NSI is misplaced. To illustrate, the vitally important Technology Innovation Agency (TIA) is short on leadership stature and financial capacity and has largely failed to pursue and achieve the ambitious goal of facilitating and commercialising hundreds of new ventures in advanced technologies. The subcritical or misplaced entities, such as the NIHSS and SANEDI, require specific remedial interventions.

11. There is considerable investment and research (over 7% of gross expenditure on R&D) in the field of environmental sciences with multiple stakeholders across a range of industry sectors, government departments, research agencies, universities and non-profit research organisations. However, the institutional capacity analysis revealed that there is no environment, marine and earth sciences council, despite the vibrant research activity and investment in researcher training. The extensive but fragmented research activity that currently defines this sector is sub-optimal and out of sync with the global significance of South Africa's biodiversity and environmental conservation programmes and this should be remediated.

12. As was the case with the creation of the NIHSS to reinvigorate the Humanities and Social Sciences, consideration should be given to the establishment of a National Institute for Engineering and Advanced Digital Sciences and Technologies, to be incorporated into a reconfigured system of entities.

13. There are strong indications that some government departments do not provide appropriate strategic guidance and oversight to their science councils and other research institutions. These science councils and other research entities were created by their founding departments of state to serve their respective priorities and stakeholders. In some cases, over time, the relationship between the parent departments and their research institutions have weakened or completely collapsed.

The implications of the above issues and findings are far-reaching. Already, there are strong indications in the available data sets that South Africa's negative technology balance of payments is persistently wide[256]. The spectre of de-industrialisation is no longer a threat but a present and growing economic reality[257]. South Africa remains enmeshed in a decades-long middle-income trap with a negative prognosis[258]. At this rate, the NDP objectives of rolling back unemployment, poverty and inequality are regrettably unlikely to be achieved. The social and humanitarian ramifications of such a forecast catastrophic failure are too appalling to countenance.

[256] NACI. 2020. A Review of the National Research and Development Strategy and (NRDS) and Ten-Year Innovation Plan (TYIP). NACI: Pretoria.
[257] Andreoni, A., & Tregenna, F. (2018). Stuck in the Middle: Premature Deindustrialisation and Industrial Policy. CCRED Working Paper 11/2018.
[258] Felipe, J., Abdon, A., & Kumar, U. 2012. Tracking the Middle-Income Trap: What is it, who is in it, and why?. Working Paper No 715, Levy Economics Institute of Bard College, Annandale-on-Hudson. New York.

6.2 An urgent need to pivot the system

The above compendium of gaps and shortcomings suggests a need to pivot the HESTIIL on an urgent basis. Both the NDP and the STI White Paper call for addressing the fragmentation of the NSI at the system and programme levels. Time-series analyses of various NSI indicators suggest that the current crisis has been long in the making, particularly so in the last decade[259].

On the policy front, the inducements that came with the 1996 White Paper on Science and Technology and followed up by the National Research and Development Strategy have run their course, and these have taken the NSI as far as they could. The institutional and governance mechanisms that were proposed by these policies have either been implemented, postponed or ignored, as the case may be[260]. These include, among several others, the establishment of organisations such as TIA and the implementation of the Strategic Management Model[261]. The science and technology missions that emerged as a result of those policies have been implemented, and some have since come to an end. Recent systemic reviews paint a bleak picture in relation to some of these efforts[262].

There are further signs that are indicative of the onset of policy fatigue in the HESTIIL. The push for increased investments in higher education and research and development to support the emergence and transformation of the democratic state appears to have run out of steam. The Gross Expenditure on Research and Development (GERD) has plateaued despite increased contributions from government[263]. The existing inducements for increased expenditure by the private sector are met, at best, with only a lukewarm response[264]. The fervent call for increased support for higher education that reached a crescendo in the #FeesMustFall campaign has been subdued by the cold reality of fiscal constraints in the context of flat, and more recently, negative economic growth. In the aftermath of the COVID-19 pandemic, and the economic havoc it is leaving in its wake, the prospects of achieving the NDP target of raising the GERD to 1.5% of gross domestic expenditure (GDP) are decidedly bleak.

Even where relative success has been recorded in research and development[265], new searching questions have emerged that put a damper on these achievements. The phenomenal growth in the publication output in the past ten years has given rise to questions about the quality of the outputs – and more significantly for society and the economy – the dearth of a concomitant rise in the translation of the knowledge outputs into innovations that have a social or economic impact. The innovation chasm that has been the bane of the NSI since it was identified in the National Research and Development Strategy remains unresolved[266]. Moreover, as the country works hard to catch up with the leading industrial economies, the gap seems to grow wider as the competitors continue to set and achieve even more stretch benchmarks.

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[259] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.
[260] DST. 2017. *Ke Nako Research and Innovation for Socio-economic Impact Now! A review of the South African science, technology and innovation landscape*. Pretoria.
[261] NACI. 2020. *A Review of the National Research and Development Strategy and (NRDS) and Ten-Year Innovation Plan (TYIP)*. NACI: Pretoria.
[262] Ibid.
[263] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.
[264] Ibid.
[265] DHET. 2019. *Report on the Evaluation of the 2017 Universities' Research Output*. Pretoria
[266] Government of South Africa. 2002. *South Africa's National Research and Development Strategy*. Pretoria: Government of South Africa.

All the above signs suggest that the NSI lacks vibrancy and momentum. If it is allowed to continue on this trajectory, it will fail to live up to the NDP goals. Owing to the range and multiplicity of the weaknesses, the system will not respond optimally to piecemeal interventions. There is an urgent need for a comprehensive pivoting of the system. Incremental measures that amount to the extension of the status quo, will simply not yield the desired results. The case for an urgent system pivoting is illustrated in the accompanying diagram.

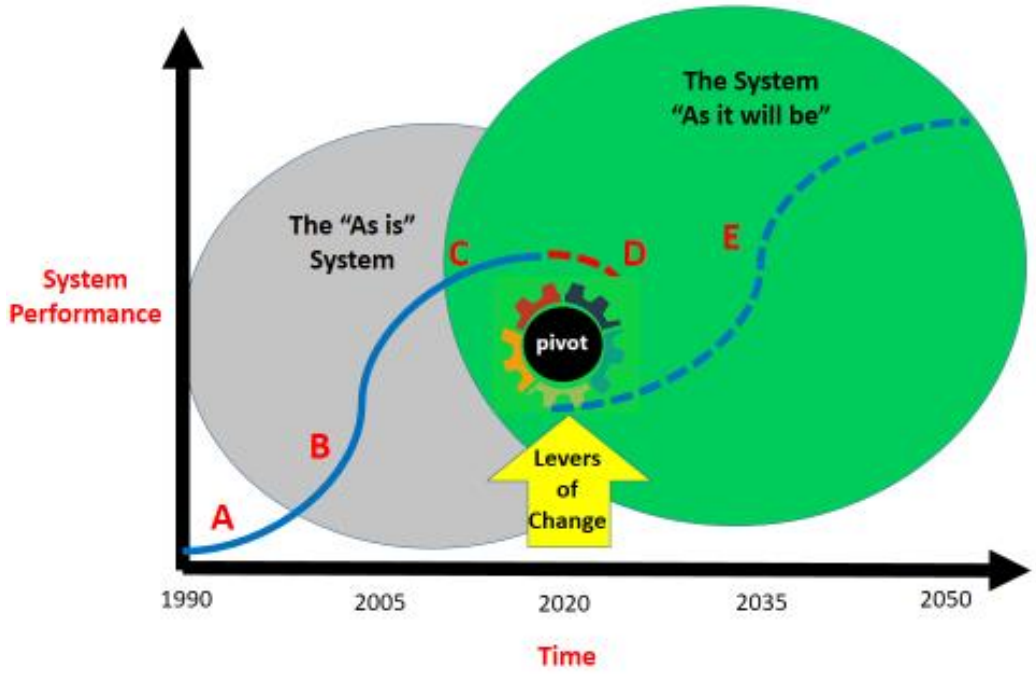

Figure 6.1: Pivot diagram – applying levers of change to tilt the current NSI to an idealised state

As shown in the accompanying figure, the NSI has undergone some changes in the past thirty years. Over this period, the system has responded to the changing policy regime as follows:

A – The system as inherited from the apartheid state, stuttering owing to international isolation.
B – Following policy inducements in 1996 and 2002, the NSI was in a buoyant state, performing well.
C – After 2010, the system is showing clear signs of stagnation and decline (as discussed above).
D – If a 'business-as-usual' approach is taken, the system will slide into regression.
E – If the proposed set of measures to pivot the system are taken, the NSI will likely grow and flourish.

In this context, pivoting is a process by which a system that is in a state of decline is transformed and tilted onto a higher and more sustainable growth path through the application of a set of inducements.

Chapter 7

Recommendations and implementation roadmap

7. Recommendations and implementation roadmap

7.1 The levers of change

To address the gaps and shortcomings that emerged from the above issues and findings, the HESTIIL Review Panel formulated a set of recommendations that are designed to pivot the system and elevate it onto a higher performance trajectory. The recommendations are organised around a set of five levers of change for the NSI. These are: Values, Governance, Resourcing, Capabilities and Coherence.

Before presenting the recommendations, we first outline the levers of change to unpack the multipronged and yet holistic process of targeted system pivoting.

Values are socially shared 'conceptions of the desirable'[267]. Values provide a bedrock of principles to guide management practice particularly during uncertain times. When the Review Panel held a consultative meeting with the leaders of the HESTI institutions, a strong call came out for the strengthening of values in leadership. At a time when public confidence in the capacity of the state is under intense examination, it is paramount to strengthen the ethical basis of the NSI by ensuring that there is alignment across the system on what it means to be a public servant, and the imperative to honour the country's Constitution.

Governance incorporates all aspects that concern political oversight, strategic management and the advisory support for the NSI. Many of the issues outlined above point to weaknesses in coordination across government and a decline in effective cooperation across all sectors of the economy. Governance therefore serves as an important lever of change for providing an organising framework for interventions that aim to improve steering and oversight of the NSI, and to combat fragmentation at a system level.

Resources encapsulates recommended actions for the optimisation of financial and other resources available to the NSI. The quest to grow investments in research and development has been a challenging one, even during the best of times, as the stubborn historical GERD trend affirms[268]. The increased fiscal pressure that is ever-present (and with more that lies ahead) places a greater premium on the need for smart investments and efficiency in the distribution and expenditure of scarce resources.

Capabilities refers to all the necessary capabilities that the institutional landscape requires to effectively manage the process of converting knowledge and know-how into commercially viable products and services. Apart from the standard innovation capabilities that are often measured as inputs in innovation surveys, there are complementary capabilities that are important[269]. The recommendations address a range of institutional capabilities essential for innovation, including complementary capabilities.

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[267] Rokeach, M. 1979. *Understanding Human Values: Individual and Societal*. The Free Press: New York.
[268] Statistics SA. 2019. *South African National Survey of Research and Experimental Development: Statistical Report 2018/18*. Pretoria.
[269] Cirera, X. & Maloney, W. F. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington DC: World Bank. https://openknowledge.worldbank.org/handle/10986/28341 License: CC BY 3.0 IGO.

Coherence encompasses the aspects that relate to forging and maintaining fruitful interactions and partnerships between various actors in the HESTIIL to address programme fragmentation. Our international benchmarking exercise has affirmed that successful innovation systems are characterised by a high level of coherence derived from closer collaboration and effective networking.

These five levers of change are used below to organise the recommendations proposed by the panel. In practice, all five levers work together in mutually reinforcing ways. When they work together effectively, a virtuous circle is created. The intended pivoting of the system, to address the identified gaps and weaknesses, is likely to succeed if all the levers of change are engaged since they are systemically linked. In this consideration, it is therefore more appropriate to conceptualise the levers of change not as separate leverage points, but as a holistic and targeted system pivoting mechanism. This requirement applies even when the interventions are scheduled for different times and locations within the institutional landscape, as it is advocated by the HESTIIL Review Panel.

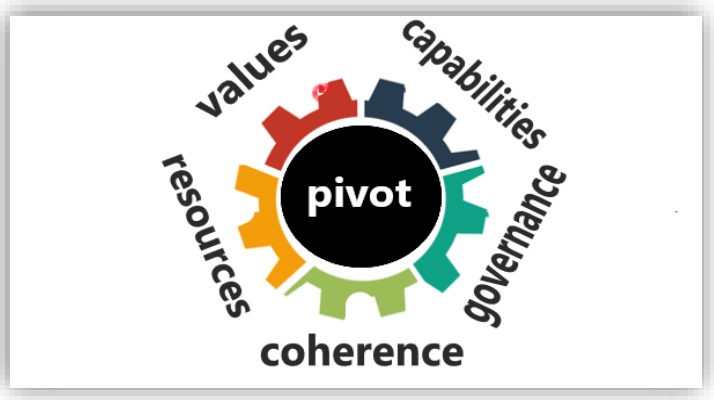

Figure 7.1. An illustration of the levers of change as a holistic pivoting mechanism for the NSI

7.2 Recommendations

The recommendations below outline the proposed interventions that are designed to pivot the NSI and tilt it towards a higher growth trajectory and performance level. The recommendations derive from a rigorous process of data analysis across all the components of the review. They are organised around the five Levers of Change outlined above.

Values

1. Future HESTI policies, plans and programmes should be grounded on the country's value system, in accordance with the growing voice of the STI community and the prevailing concerns of the broader society. The country's values base and the changing international dynamics offer opportunities for a positive discourse in this regard. The African philosophy of *Ubuntu* may provide a common foundation for rebuilding a values-based HESTIIL and for restoring public trust in state institutions and programmes, while affirming indigenous knowledge systems and their role in nation-building among other practical applications.

2. There is a need to incorporate values that are aligned with entrepreneurship within the country's innovation discourse to support the overall thrust of STI policies. The multimodal promotion of entrepreneurial values, among all sectors of the population, will help to create an enabling environment for technology-based enterprise development initiatives, including

training. Japan offers a good example of an industrial economy that emerged on the strength of its traditional value system and the incorporation of modern demands.

Governance

3. There is a need to pivot the current HESTIIL to position the system for increased coherence and coordination, while combating fragmentation and unhealthy competition. In line with the STI White Paper, transitioning the system to the idealised landscape involves initially establishing a three-level agenda and priority setting, steering, implementation and monitoring mechanism. The components of the governance mechanism include the establishment of the Presidential Advisory Council on Science and Innovation, whose primary role is to set the agenda for the NSI through, for example, considering and approving four to five societal grand challenges or missions. The Presidential Advisory Council will be supported by an Inter-Ministerial Committee and an Inter-Departmental Committee of Directors-General. Additional details about the tilting of the HESTIIL to the idealised state are spelled out in the next section below.

4. A set of profound measures need to be undertaken to restore the vitally important role of business and industry in the local research, technological development and innovation enterprise. Such measures should include –
    - Securing business and industries' effective and authoritative participation in the Presidential Advisory Council.
    - Reviewing the existing business and industry research, innovation and technology transfer tax incentive scheme for a possible pivot to greater effectiveness and impact.
    - Establishing national and regional platforms to forge collaborations between universities, science entities, business and industry; and
    - Establishing industry-based Master's, Doctoral and Post-Doctoral programmes to strengthen networks within HESTIIL, while ensuring quality problem-focused research training.

5. A call is made to reimagine and reinvent NACI into a substantive, legitimate and competent national advisory body. In order to widen its influence, it is recommended that it should be located within the Presidency as the secretariat to the Presidential Advisory Council.

Resourcing

6. To revitalise the participation of the business sector in the NSI, consideration must be given to conducting a review of the existing business and industry research, innovation and technology transfer tax incentives (see also 4 above). Where these are found to be inadequate, the necessary improvements should be instituted, as informed by consultations with the business sector.

7. The problem of capital flight should be addressed, using all the opportunities and means at the government's disposal. Measures should be considered to reverse the decline of the BERD, both in real terms and as a proportion of the GERD. Studies should be undertaken to explore the most appropriate mix of funding sources, taking into account the objectives for an increased GERD, the dynamics of the local economy and the lessons from other comparable international economies.

Capabilities

8. Trade policies should enable an increase in the technological and social capital for local firms. The Ministries responsible for Science and Innovation, and Trade, Industry and Competition should be centrally involved in trade negotiations, so that trade agreements can be leveraged to drive industrialisation and technology transfer and nurture and catalyse indigenous firms.

9. Moreover, as evidenced in the deeply polarising stand-off between many OECD countries and China, note should be taken of the risks and opportunities that arise within the ever-evolving political economy of the global NSI. Appropriate science and knowledge diplomacy measures and actions such as has been successfully achieved in the instance of the SKA programme, should be undertaken to support the elevation and deepening of the country's NSI.

10. In addition to instituting a programme of industry-based research studies, it is recommended that postgraduate studies and publications within engineering and its allied disciplines (such as computer, information and advanced digital sciences and technologies) should be urgently supported. Such action would pivot the skills base towards innovation-supporting capabilities. Additionally, it is recommended that a new Advanced Engineering and Digital Technologies Science Institute to catalyse this nascent industry be created and established within the NRF. Such an action would not be dissimilar to the establishment of the National Institute for Humanities and Social Sciences.

11. There is a need for a reconceptualisation of the NSI to better position it for addressing unemployment, poverty and inequality. This can be achieved, among other means, by a comprehensive articulation of inclusive innovation, and a delineation of the NSI to accommodate the voices and participation of the marginalised communities. Policy-makers and practitioners should take every available opportunity to equip themselves with the necessary knowledge and skills required for tilting the NSI towards real inclusive innovation.

12. To get close to achieving the NDP outcomes, the country's research capacity must be scaled up considerably, with a purposeful prioritisation of research and full-time researcher growth in critical areas for the economy and society. In this respect, the call for studies on the appropriate interventions to squarely address hunger, malnutrition and poverty is reinforced. The proposed Research Development and Innovation missions can provide the necessary focus for capacity building in areas that address head-on the fundamental needs of the South African people.

Coherence

13. A centralised single National Foundation for Research and Innovation (NFRI) should be established by 2030 to bring under one umbrella the various entities in the innovation system value chain, from those performing basic research to technology transfer, innovation and commercialisation entities. This would create a seamless innovation funnel that ensures that there are no chasms that stifle industrialisation. It is recommended that the NFRI be created from the consolidation and clustering of existing agencies into councils/fields/clusters according to their key areas of focus, and placing them under one implementation agency that will facilitate the innovation activities within the clusters. In this regard, the pathway for the establishment of United Kingdom Research and Innovation (UKRI), and similar implementing agencies in other peer nations is instructive. Establishing the NFRI would add the fourth tier of the national coordinating system (see recommendation 3).

14. To address the poor coordination and lack of integrated planning between the DSI and DHET, an inter-departmental planning, coordinating and system steering mechanism must be established. Similar interventions can be considered in relation to other government departments that ought to be working closely in the interest of an integrated HESTIIL.

15. A call is made for the state to use its considerable procurement muscle to stimulate and deepen domestic technology transfer and industrial innovation by setting aside a percentage of the state procurement spend for promoting local innovation.

16. The cross-cutting stewardship and oversight mandate of the Department of Environment, Forestry and Fisheries is well recognised, however the research intensity in both the basic and applied fields in the environmental sciences warrants dedicated coordination by the DSI under a new environmental and climate change research council. It is envisaged that such a new research entity would fall under the umbrella of the proposed National Foundation for Research and Innovation as detailed in recommendation 13.

17. Innovation policies need to consider the intricacies of the local political economy in order to navigate and leverage the polar tendencies that are prevalent within and across the private and public sectors. A failure to recognise and accommodate these driving forces within the country's political economy will undermine the achievement of inclusive innovation and a transformed economy. Conversations with the private sector should include identifying anchor points for a shared worldview and the development of a social compact within the system.

7.3 Elaboration on the pivoting mechanism

The most significant remedy that we present in this report for the incoherence and silo state that prevails in the NSI, is the pivoting of the HESTIIL towards an institutional arrangement that will redress fragmentation, improve system performance and monitoring, and promote cooperation and the development of synergies. Once properly configured, the reconstructed HESTIIL will be in a position to deliver on the NDP objectives and enhance social and economic impact through targeted use of incentives, grants and other policy instruments. The HESTIIL Review Panel is convinced that the measures contained in this report, which are motivated by the NDP, are consistent with and can be implemented under the banner of the STI White Paper.

To support the recommendations outlined above, we provide further details on the key components of the pivoting of the HESTIIL that is proposed. In particular, we elaborate by presenting an outline of the elements that constitute the spine of the reconfigured HESTIIL, viz:

- The proposed steering mechanism or governance structure (i.e. the coordinating framework);
- A reconfigured institutional base for implementing all the approved RDI programmes of the NSI, including the grand challenges (under the stewardship of the new National Foundation for Research and Innovation); and
- The suggested catalytic transdisciplinary societal grand challenges (or missions).

7.3.1 The National Coordinating Framework

As part of transitioning to the idealised landscape, we propose the establishment of a four-level agenda and priority setting, steering, implementation and monitoring mechanism, to be constituted as follows:

- *The Presidential Advisory Council for Science and Innovation*

  The Presidential Advisory Council for Science and Innovation will be chaired by the President. It will comprise high-level representatives from the cross-section of the NSI, including business, industry, government, higher education, non-governmental organisations and civil society. The principal role of the Presidential Advisory Council will be the setting, reviewing and updating of the country's mid- and long-term policy agenda for science, technology, innovation and industrialisation. The Council will also consider and provide specific advice, knowledge and guidance to government, such as in the instance of the Research Development and Innovation societal grand challenges or missions. It will also publish medium-term agendas or strategy documents for research, innovation and industrialisation. A reconstituted, as well as mission- and capacity-reinforced, National Advisory Council on Innovation (NACI) will provide advisory and secretariat support to the Presidential Advisory Council.

- *Inter-Ministerial Panel*

  Operating under the oversight of the Presidential Advisory Council will be a panel of ministers from all the sectors that have a critical stake in higher education, science, technology and innovation. Chaired by the Minister of Higher Education, Science and Technology, the Inter-Ministerial Panel will be responsible for steering, monitoring, evaluation and remediation (when and where required) of the NSI.

- *Inter-Departmental Group*

  The Inter-Departmental Group is a Director-General (DG)-level structure that will include apex leaders of universities, science councils and agencies organised within knowledge, innovation and technology transfer and industrialisation fields/clusters/councils. The Inter-Departmental Group will be responsible for implementing the NSI agenda, inclusive of all programmes and societal grand challenges/missions.

- *The National Foundation for Research and Innovation*

  As a long-term goal, i.e. to be finalised by 2030, the various HESTIIL entities will be reconstituted into the National Foundation for Research and Innovation (FRI). The NFRI constitutes the science, technology and innovation muscle of the NSI. Details on the NFRI are discussed below.

In summary, the National Coordinating Framework will address the fragmentation and incoherence that is endemic to the NSI, through high-level steering and agenda setting, integrated monitoring and evaluation, and coordinated implementation plans. These will be executed through an appropriately resourced inter- and transdisciplinary institution that is primed for tilting the performance of the NSI towards the achievement of the NDP goals.

At a glance, the National Coordinating Framework is constituted as follows:

	Presidential Advisory Council	Inter-Ministerial Panel	Inter-Department Committee	National Foundation for Research and Innovation
Role	Agenda setting	Steering, monitoring and evaluation	Implementation of NSI agenda	Funding, coordination
Level	Presidency	Ministerial	Director-General	Official
Type	Oversight	Steering	Working group	Agency
Composition	High-level leaders from business, industry, HET, government, civil society and NGOs	Cabinet ministers from relevant ministries	DGs, apex leaders from universities, science councils, business, industry	CEOs of all the reconfigured RDI entities across the whole innovation value chain

Table 7.1: The National Coordinating Framework
(NB: The NFRI and NACI are not included in the above table.)

7.3.2 The National Foundation for Research and Innovation (NFRI)

Transition from the 'as is' to the 'idealised' state will culminate in the establishment of the proposed National Foundation for Research and Innovation (NFRI) via a gradual and initial modest resetting process of the current system to achieve greater inter-connectedness, collaboration and partnership. The NFRI will bring under one umbrella various entities in the innovation system value chain – from those performing basic research, to innovation and technology transfer to commercialisation entities. As the national implementing agency, it would create a seamless innovation funnel to ensure that there are no chasms that stifle industrialisation and the achievement of the country's economic and social goals.

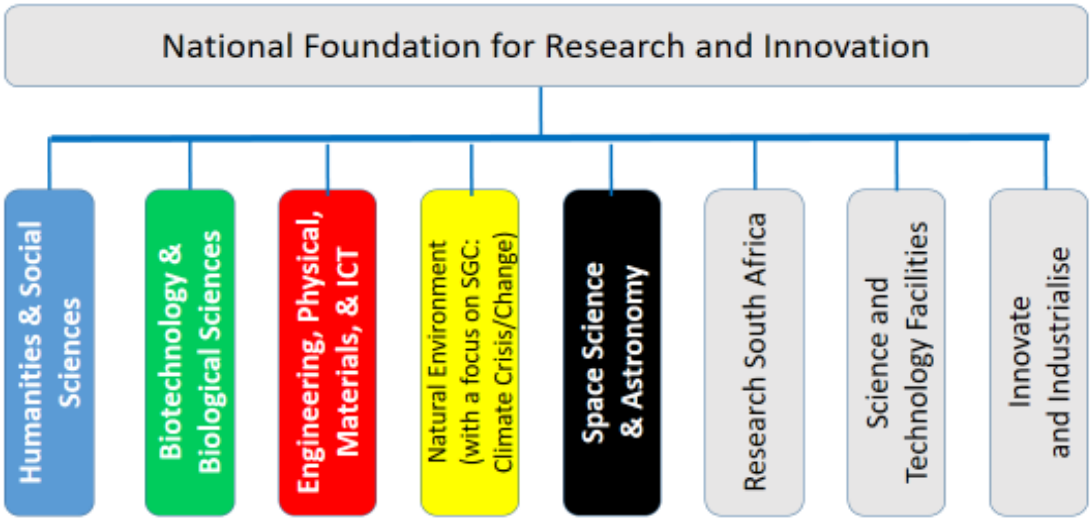

Figure 7.2: An indicative institutional model for an idealised HESTIIL*
(*The RDI disciplines of the new entities under the FRI can be organised in different permutations.)

When it is fully set up, the National Foundation for Research and Innovation will assume the responsibilities for the coordination and implementation of the country's multidisciplinary STI agenda

across the entire RDI value chain. The NFRI will constitute the final piece of the National Coordination Framework under the oversight of the Presidential Plenary, as illustrated below.

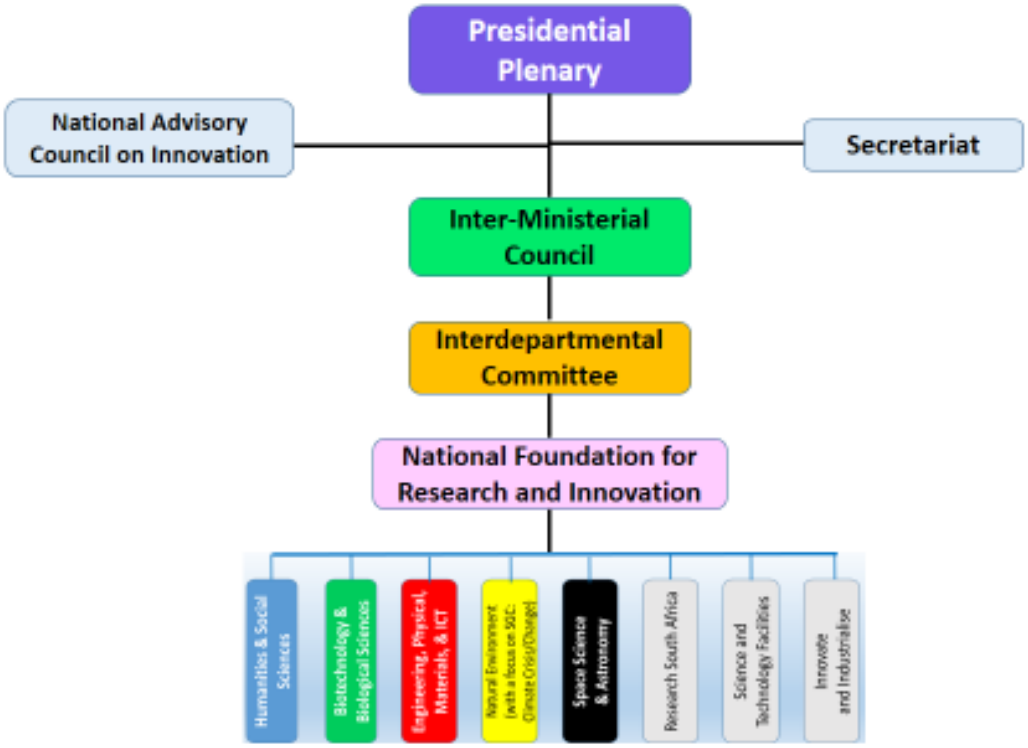

Figure 7.3: Illustration of the National Coordination Framework

7.3.3 The Research, Development and Innovation Missions

In conducting the capacity analysis of HESTIIL, the Review Panel gave considerable focus and attention to examining the size, shape, direction, responsiveness and impact of the research and innovation and the higher education systems. This included the identification and examination of Research Development and Innovation (RDI) activity and capacity across the NSI that is aligned with the STI White Paper, the National Plan for Post-School Education and Training as well as the Report of the NACI Foresight Study.

The pivoting of the HESTIIL to address the existing gaps and shortcomings should take place alongside a reconfiguration of the research agenda to add a special focus on the key developmental challenges facing the country. To this end, the practice of identifying transdisciplinary societal grand challenges or missions is appropriate. The RDI missions will help to catalyse concentrated focus, for given periods of time, to respond to some of the key socio-economic challenges of the country. While the overall STI agenda will continue to be implemented across the HESTI landscape, in accordance with the approved national and organisational plans, the societal grand challenges or missions will earmark special domains that require sustained RDI activity.

Our system capacity analysis and an in-depth examination of the NDP goals led to the identification of four RDI areas that could constitute the catalytic missions for a re-imagined HESTIIL and a socially responsive agenda. The four proposed missions met all the criteria that were applied to this

prioritisation exercise. They also support the country's value system and would contribute towards tilting the system towards greater collaboration.

Arising from the analysis of the HESTIIL Review Panel, the following four societal grand challenges or missions are recommended for implementation:

V. **Health and Well-Being** – which would allow us to put in place proactive efforts to deal with all communicable diseases that affect our communities, improve life expectancy and achieve food sovereignty and nutritional democracy.

VI. **Climate Crisis/Change** – sustaining the integrity and enhancement of our ecosystem services and their relation to an improved quality of life.

VII. **Work, Livelihoods in a Changing Technological World** – responses that redress vital gender, race, class, generational, income and household inequalities; and

VIII. **Learning, Education and Scholarship for a Future Society** – to enhance the proactive scientific, technological and interpretative capacities in the system [270]

The above priority societal grand challenges or missions offer distinct advantages:

- They outline programmatic areas to direct multi- and transdisciplinary RDI initiatives over and above the traditional research agendas of the NSI and its institutions.
- They provide a platform for the country's priorities to be succinctly communicated with increased clarity and precision to all the country's citizens and other stakeholders.
- The missions can form the bases for coordination across multiple silos in the existing system, within and between government departments, business and industry and civil society.
- They are well-positioned to indicate where the opportunities for the scaling up of the NSI should be, as well as the priority areas for developing capabilities for innovation; and
- Over time, the four missions can provide a platform for South African excellence in some of the most important global challenges, particularly in the developing world.

The process of consolidating the existing programmes into four missions can be accomplished within the framework of the institutional reconfiguration outlined above. This could be done without causing unnecessary disruptions given that the proposed missions are consistent with many elements of the recent priority setting exercise conducted by NACI. For instance:

- **Health and Well-Being** – it was already prioritised as a medical/social research terrain; it could encompass 'Nutrition for a Healthy Population' and the proposed 'Nutrition, Food Security and Food Sovereignty' as well as the focus on 'Health Technologies'.

- **Climate Crisis/Change** – can absorb the priorities around 'Integrated Solutions for Water Security' and enhance the already identified priority in 'Earth Sciences, Climate Change and Water Security'.

- **Work, Livelihoods in a Changing Technological World** – could absorb initiatives in the 'Circular Economy' cluster, a 'High-tech Industry domain', the 'Opportunities and Impact of ICTs', the 'Marine Sciences and the Ocean Economy', 'Sustainable Energy Mixes' and 'Industrial Diversification and the Future of Jobs'.

[270] After carefully listening to the Decadal Plan ideas for Challenges, we were convinced to take out 'Learning' from Challenge 3 because it pertained to all other areas as well and creates an area in its own right.

- **Learning, Education and Scholarship for a Future Society** – could absorb the 'Education for the Future' and 'Sustainable Technologies for the Marginalised and the Future of Society'.

Further work that supported the identification of the above missions, and possible reconfigurations that will enable their success, include network mapping. The mappings are based on financial connectivity in all four priorities to give a tangible indication of the state of the respective innovation ecosystems. A full description and presentation of the networking exercise is contained in the comprehensive Review Report.

7.4 Implementation roadmap

As alluded to above, the shift towards an idealised HESTIIL should be phased in over the next ten years. It will build on existing initiatives, with resource efficiency in mind, via a transitional resetting in the next five years, to develop interconnected collaboration and partnership. This will involve a gradual and well-considered migration of entities to the National Foundation for Research and Innovation (see figure below). It is recommended that sufficient time – up to ten years – is allowed for the new entities to be located under the coordination and control of the NFRI, to ensure a thorough and well-considered process with minimum disruption.

While the proposed pivoting of the HESTIIL is profound and far-reaching, the Panel is of the opinion that it can be achieved without causing any disruptions to the functioning of the system. Every care should be taken not to disturb ongoing work or upset key administrative and reporting processes. With this in mind, the Panel proposes a three-stage process that will organise the phasing in of the recommendations. This provides an outline of an implementation roadmap for this review. The three-stage outline of the roadmap is designed to phase in the interventions in a systematic manner so that the transformation takes place smoothly. The key recommendations pertaining to the proposed National Coordination Mechanism and the establishment of the National Foundation for Research and Innovation are outlined in the roadmap.

	PHASE 1	PHASE 2	PHASE 3
	0-2 years	2-5 years	5-10 years
Coordinating mechanism	• Set up Presidential Plenary, Inter-Ministerial Panel and Inter-Departmental Committee	• Governance mechanisms in place and oversee system transformation	• Oversee system review • Approve next decadal plan
National Foundation for Research and Innovation	• Communication and consultations with stakeholders • Set up a transitory coordinating structure	• Initiate legislative processes to establish the NFRI • Coordinating structure is finalised	• Migration of existing entities to the NFRI • Coordinating of entire RDI value chain is complete
National Advisory Council on Innovation	• Initiate legislative process to elevate mandate and strengthen resourcing • Set up transitory arrangements to support new governance protocols	• NACI in place as Advisory and Secretariat to the Presidential Plenary • Migration of NSI evaluation capacity and mandate	• NACI fully functional as advisory council to the system at national level
Grand Challenges	• Consultations and finalisation of the missions • Budgeting and implementing entities outlined	• Full implementation in place • Monitoring mechanisms in place	• System evaluation and review

Table 7.2: indicative implementation roadmap

7.5 Conclusion

As demonstrated in this Review Report, South Africa's NSI is at a crossroads. If the status quo is allowed to continue, the NSI will continue to underperform, and will remain plagued by incoherence and discordance. In such an instance, the NSI will fail to generate the benefits of the knowledge economy envisaged by the NDP.

The Review Panel has identified several measures that could be implemented to pivot the HESTIIL towards increased collaboration, coherence and innovation. The strategic levers of change entail:

- A **values** base that is consistent with the NDP vision.
- Institutional **governance** that will ensure collaboration and coordination.
- A smart **resourcing** plan that will optimise and sustain the funding base for HESTI.
- The enhancement of the necessary **capabilities** for innovation and management.
- A measured and progressive implementation of institutional changes and RDI societal grand challenges or missions to deliver system **coherence** and synergy.

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