A REVIEW OF

THE NATIONAL RESEARCH AND DEVELOPMENT STRATEGY (NRDS) AND TEN-YEAR INNOVATION PLAN (TYIP)

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NACI
NATIONAL ADVISORY COUNCIL ON INNOVATION

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for a better future

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NATIONAL ADVISORY COUNCIL ON INNOVATION

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ACRONYMS AND ABBREVIATIONS[1]

AMTS	Advanced Manufacturing Technology Strategy
ARC	Agricultural Research Council
BRICs	Biotechnology Regional Innovation Centres
BRICS	Brazil, Russia, India, China and South Africa
CeSTII	Centre for Science, Technology and Innovation Indicators
CHE	Council on Higher Education
CoE	Centre of Excellence
COHORT	Committee of Heads of Organisations for Research and Technology
CREST	Centre for Research on Evaluation, Science and Technology
CSIR	Council for Scientific and Industrial Research
DACST	Department of Arts, Culture, Science and Technology
DBE	Department of Basic Education
DHET	Department of Higher Education and Training
DPME	Department of Planning, Monitoring and Evaluation
DSI	Department of Science and Innovation
DST	Department of Science and Technology
dti	Department of Trade and Industry
FTE	Full-Time Equivalent
FTI	Foundation for Technological Innovation
HCD	Human Capital Development
HEI	Higher Education Institution
HRD	Human Resource Development
ICT	Information and Communication Technology
IDC	Industrial Development Corporation
IK	Indigenous Knowledge
IKS	Indigenous Knowledge Systems
IP	Intellectual Property
IPMO	Intellectual Property Management Office
IPR	Intellectual Property Rights
KPA	Key Performance Area

[1] Note that the acronyms and abbreviations listed here are not comprehensive; rather, they cover the most frequently used terms in the main report. Individual strategy-/intervention-specific acronyms are footnoted in the text.

KPI	Key Performance Indicator
MoU	Memorandum of Understanding
MRC	Medical Research Council
MTEF	Medium-Term Expenditure Framework
NACI	National Advisory Council on Innovation
NDP	National Development Plan
nGAP	New Generation of Academics Programme
NIPMO	National Intellectual Property Management Office
NRDS	National Research and Development Strategy
NRF	National Research Foundation
NRTA	National Research and Technology Audit
NSI	National System of Innovation
PFMA	Public Finance Management Act
R&D	Research and Development
RDI	Research ,Development and Innovation
S&T	Science and Technology
SANReN	South African National Research Network
SciSTIP	DSI/NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy
SET	Science, Engineering and Technology
SETIs	Science, Engineering and Technology Institutions
SKA	Square Kilometre Array
SMEs	Small and Medium Enterprises
SMM	Strategic Management Model
SMMEs	Small, Medium and Micro Enterprises
STI	Science, Technology and Innovation
SU	Stellenbosch University
THRIP	Technology and Human Resources for Industry Programme
TIA	Technology Innovation Agency
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
TRL	Technology Readiness Level
TTO	Technology Transfer Office
TUT	Tshwane University of Technology
TYIP	Ten Year Innovation Plan
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
USAf	Universities South Africa
UWC	University of the Western Cape
WIPO	World Intellectual Property Organization
Wits	University of the Witwatersrand

FOREWORD

The Minister of Higher Education, Science and Innovation (previously known as Science and Technology) mandated the National Advisory Council on Innovation (NACI) to review the National Research and Development Strategy (NRDS) and Ten-Year Innovation Plan (TYIP). The outcome of this review was viewed as a necessary basis of constructing a new Ten-Year Innovation Plan.

The NACI Council defined the purpose of the review as to conduct a retrospective assessment of the NRDS and TYIP, which were the instruments used for the implementation of the 1996 White Paper on Science and Technology's broad vision and framework of STI activities. The review was seen as the first major review of the two policy instruments since their establishment. The review needed to find a way of identifying, mapping and reflecting on all activities or policy initiatives (within and without DSI) in order to develop a better understanding of the progress or lack of progress in implementing the two policy instruments.

The review needed to provide deeper insights into the dynamics of policy implementation or lack of implementation. The emphasis was on the lessons learnt, to advise on what worked or did not work, to recommend actions to address current policy gaps, and to inform the development of future strategies or plans. The intention was to ensure that review results could find immediate application in the development of the new decadal plan for STI.

The review started in January 2019 and was concluded in May 2020. The Council recognises that while the review process began in a largely business-as-usual context, by the time it came to synthesising the research findings and finalising the recommendations, COVID-19 had changed the global situation dramatically. The review report will be received in a world facing even more acute social and economic crises than the ones we have endured to date.

All NSI actors need to consider what to take and use in shaping a post-COVID STI system that is responsive and relevant to the post-COVID South African society and the world. I am pleased to present this report which covers the outcome of the extensive work undertaken by the evaluation team. I particularly wish to draw attention to the conclusions and recommendations, which formed the basis of advice submitted to the Minister of Higher Education, Science and Innovation.

Dr Mlungisi Cele

Acting CEO
National Advisory Council on Innovation

PREFACE AND INTRODUCTION

The commission by NACI within the national context of policy and strategy design

SciSTIP was commissioned late in 2018 by the National Advisory Council on Innovation to undertake a retrospective assessment of the National Research and Development Strategy (NRDS) (DST, 2002) and Ten-Year Innovation Plan (TYIP) (DST, 2008). The final agreement to undertake this study was signed in mid-January 2019, at which point the team was assembled to start the study. Because of delays in finalising the contract, the team suspended its work for about ten weeks between May and July 2019.

The review commenced during the same year (2019) that the final version of the White Paper on Science, Technology and Innovation (DST, 2019) was accepted by Cabinet, as well as the publication of the (much delayed) South Africa Foresight Exercise for Science, Technology and Innovation 2030 Report (DSI/NACI, 2019). Although not defined in the Terms of Reference as an input into the Department of Science and Innovation's (DSI) new Decadal Plan (under construction), the team was aware of the fact that the results and recommendations of this study would eventually be read and received within this context.

A note on nomenclature

Throughout this report, reference is made to the 'DST' in discussions relating to documents, events and initiatives that took place prior to the reconfiguration of the department into the Department of Science and Innovation (DSI) following the May 2019 Cabinet reshuffle. The term 'DSI' is used in the present and future tense (i.e. at the time of writing this review report).

Reference is also made to the two-level system ministerial reviews undertaken in 2012 and 2017; namely, the 2012 Ministerial Review Committee on the Science, Technology and Innovation Landscape,[2] and the 2017 Ministerial Review Panel on the Science, Technology and Innovation Institutional Landscape.[3] In abbreviated form, these are referred to as the 2012 Ministerial STIL Review and the 2017 Ministerial STIIL Review, respectively.

2 DST. 2012. Ministerial Review of the Science, Technology and Innovation Landscape in South Africa. Pretoria: Department of Science and Technology.
3 DST. 2017. Ministerial Review of the Science, Technology and Innovation Institutional Landscape in South Africa. Pretoria: Department of Science and Technology.

Structure of the report

The report comprises an executive summary and five volumes:

- Volume 1 presents the background and context to the study (Terms of Reference), how the study was conducted (process and methodology), and the analytical framework that was used to analyse and present the findings of the study.
- Volume 2 is devoted to a discussion of the (high-level) assessments of the NRDS and TYIP as strategic frameworks.
- Volume 3 presents the main findings and recommendations of the study as extracted from the individual reviews of the 21 subsidiary strategies/interventions, and is organised under the following headings:
  - System-wide governance, legislation, and monitoring, evaluation and learning (MEL)
  - Human resources for S&T
  - Science and indigenous knowledge systems
  - Technology strategies and missions
  - The grand challenges
  - Financing
  - Volume 4 presents our final reflections and recommendations.
  - Volume 5 contains the detailed individual review reports.

The team and their contributions

Authors' contributions to main report

Report section	Contributing authors
Executive summary	Johann Mouton (main author and compiler)
Volume 1	Johann Mouton (main author) with critical input from Tracy Bailey
Volume 2	Johann Mouton (main author of Chapters 1-3); Thomas Auf der Heyde contributed significantly to the overview and summary of the NRDS and TYIP; Milandré van Lill and Isabel Basson were the main contributors to the indicator-based assessment in Chapter 4
Volume 3	Summary and integration (by Johann Mouton and Tracy Bailey) based on the reviews as completed by individual team members
Volume 4	Reflections and recommendations (Johann Mouton main author incorporating various inputs by team members)
Volume 5	Individual review authors with critical comments from other team members

Individual reviews of subsidiary strategies and interventions

Review	Reviewers
System Governance	Thomas Auf der Heyde
Intellectual Property	David Walwyn
Technology Innovation Agency	Michael Kahn
Innovation Fund	Michael Kahn
R&D Tax Incentive	David Walwyn
International Cooperation	Thomas Auf der Heyde
DST/NRF Centres of Excellence Programme	Jan Botha
South African Research Chairs Initiative	Jan Botha
Human Capital Development Strategy for Research, Innovation and Scholarship	Milandré van Lill and Johann Mouton
Astronomy	Michael Kahn

Review	Reviewers
Palaeosciences Strategy	Milandré van Lill and Johann Mouton
Marine and Antarctic Sciences	Heidi Prozesky
Indigenous Knowledge Systems	Isabel Basson
Resource Beneficiation and Advanced Manufacturing Technology Strategies	David Walwyn
Information and Communication Technologies	Michael Kahn
National Nanotechnology Strategy	Margaret Ward
Bio-Economy Grand Challenge	Ntsane Moleleki
Space Science and Technology Grand Challenge	Michael Kahn and Milandré van Lill
Energy Security Grand Challenge	David Walwyn
Global Change Grand Challenge	Isabel Basson
Human and Social Dynamics Grand Challenge	Nelius Boshoff

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- Ben Durham (DSI)
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- Luci Abrahams (University of the Witwatersrand)
- Sagren Moodley (DSI)
- Val Munsami (South African National Space Agency)

In addition, the following individuals attended some of the team meetings and made valuable comments and inputs:

- Rasigan Maharajh (Tshwane University of Technology)
- Nico Cloete (SciSTIP)
- Charl Albertyn (SciSTIP)
- Rein Treptow (SciSTIP)

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Johann Mouton
Stellenbosch

EXECUTIVE SUMMARY

Navigation

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- Human resources for scienc and technology
- Science and knowledge generation: Science missions
- From technology strategies to enabling and cross-cutting technolgy platforms
- The grand challenges
- System governance and policy coordination
- Financing of research and innovation

III. Strategy design

IV. Monitoring, evaluation and learning

V. Further research and reviews

I. HIGH-LEVEL ASSESSMENT OF THE NRDS AND TYIP

Governments have a number of clearly defined roles and responsibilities to ensure that science, technology and innovation (STI) priorities in a country are addressed in an effective and efficient manner. Policy debates over many decades have raised questions about how this ”mandate” should be exercised. STI systems do not exist in isolation: they are embedded in, and influenced by other social systems in a country as well as international developments. The size and shape of the STI system differs from country to country which leads to differences in the ways that governments address the main challenges of the system. Nevertheless, there is consensus in the literature that governments must assume responsibility for at least the following functions :

- Establish appropriate governance structures and systems to ensure timely and effective priority-setting and resource allocation for the STI activities in a country;
- Create an optimal policy, legislative and regulatory framework for the STI system;
- Ensure the growth of the STI system through growth in institutional capacity and infrastructure and ensuring clear differentiation and articulation of institutional missions and mandates;
- Ensure optimal financing of the STI system, both for public R&D as well as private investment in R&D; and
- Establish and maintain appropriate modes of monitoring and evaluation (M&E) of the performance of the system to ensure accountability, value for money and policy learning.

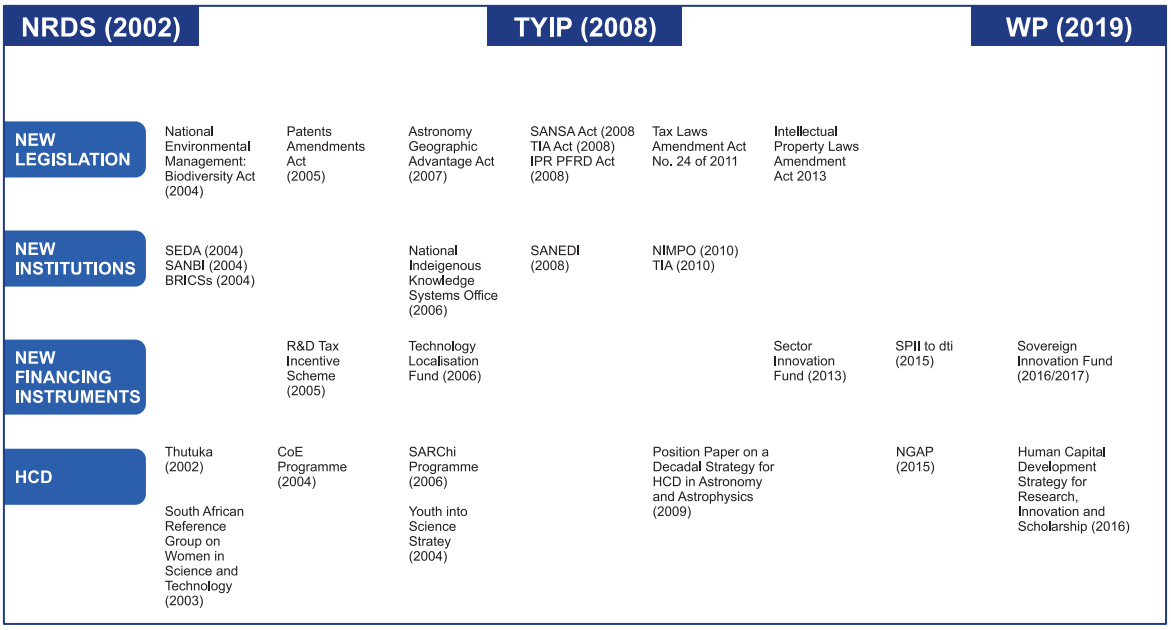
Together these functions are often defined as the necessary ‘framework components’ or ‘enablers’ that need to be (put) in place to produce the anticipated performance of the STI system in research and innovation. These introductory comments suggest that our review of the National Research and Development Strategy (NRDS) and the Ten-Year Innovation Plan (TYIP) had to address at least two broad questions:

1. To what extent has the NRDS/TYIP addressed the key system enablers (legislation, institutional change, financing and human capital development) of the South African STI system?
2. To what extent have the subsidiary strategies and interventions referenced in the NRDS and TYIP, produced the outcomes and achievements as anticipated?

The first two questions were addressed in detail in our review at two levels of assessment: (1) the outcomes and achievements of the NRDS and TYIP as system-wide policy (framing) documents; and (2) the outcomes and achievements of the individual strategies and interventions that were referenced in these two documents.

1. To what extent have the NRDS and TYIP addressed the key system enablers (legislation, institutional change, financing and human capital development) of the STI system?

The graph below presents a chronological overview of the main 'initiatives' that were implemented as a result of the NRDS and TYIP.



The graphic shows that:

- No less than eight pieces of legislation pertaining to the STI system were enacted.
- No less than eight new institutions or agencies were established.
- No less than six new funding instruments were established. In addition, funding instruments related to seed funding, technology diffusion and commercialisation, technology cluster funding, regional innovation and others were brought together under the Technology Innovation Agency (TIA).
- In addition to the major initiatives – the Thuthuka, Centres of Excellence (CoEs) and South African Research Chairs Initiative (SARChI) programmes,the National Research Foundation (NRF) also initiated a number of other Human Capital Development initiatives over the past two decades. These includes specific funding instruments added to the NRF portfolio over time to strengthen Human Resources Development in specific fields (astronomy, statistics) or for specific target groups (women, young academics).

Between the NRDS and TYIP a number of strategies and programmes were identified to support strategic areas of *scientific research* (astronomy, palaeosciences, marine and antarctic sciences, and indigenous knowledge systems), five *grand challenges* (bio-economy, energy security, global change, space science and technology and human and social dynamics), as well as a number of *technology missions and programmes* (biotechnology, information and communication technology, advanced manufacturing and materials, technology for poverty reduction, resource-based technology, the technology localisation programme, and nanotechnology). The table below summarises the main strategies, plans and roadmaps identified in the NRDS and TYIP as these were developed between 2002 and 2019.

Science missions and grand challenges: Strategies and plans	
2002	A National Advanced Manufacturing Technology Strategy for South Africa
2004	Indigenous Knowledge Systems Policy
2005	Draft Antarctic Research Strategy for South Africa
2006	National Nanotechnology Strategy SEDA Technology Programme (integrating Godisa and Technology Programmes)

Science missions and grand challenges: Strategies and plans	
2007 2007	ICT Research and Development and Innovation Strategy Hydrogen and Fuel Cell Technologies RDI Strategy Hydrogen and Fuel Cells Energy Research, Development and Innovation Roadmap
2008	Draft Energy Research Development and Innovation Strategy National Sustainable Development Framework (Global Change Grand Challenge) Global Change Grand Challenge Implementation Framework Nanoscience and Nanotechnology 10-Year Research Plan
2009	National Space Policy 10-Year Global Change Research Plan for South Africa
2010	National Space Strategy Strategic Framework for the Human and Social Dynamics in Development Human and Social Dynamics in Development Grand Challenge Science Plan
2011	Draft South African Strategy for the Palaeosciences National Climate Change Response White Paper
2013	Bio-economy Strategy ICT RDI Roadmap: Towards Digital Advantage
2014	Strategy for the Palaeosciences: DST Implementation Plan, 2014-2020 National Marine Research Plan for South Africa, 2014+ South African Antarctic and Southern Ocean Research Plan 2014–2024 Operation Phakisa: Oceans Economy Nanotechnology Innovation Roadmap
2015	National Strategy for Multi-Wave Length Astronomy and NRF implementation plan via its Astronomy sub-agency Solar Energy RDI Roadmap
2016	Strategy for the Palaeosciences Incorporating Palaeontology, Palaeo-anthropology and Archaeology South African Marine and Antarctic Research Strategy Draft Marine and Antarctic Research Strategy Implementation Plan Science Engagement Strategy
2017	5-Year Strategic Framework for the South African National Space Agency
2019	IK-based Technology Innovation Five Year (2020-2025) Action Plan

It is evident from these overviews that the majority of the STI initiatives identified and referenced in the NRDS and TYIP were adopted and implemented in subsequent years. Essential legislation (relating to protecting our biodiversity, intellectual property, and astronomic advantage) was enacted; major new agencies (the TIA and the South African National Space Agency) and offices (National Intellectual Property Management Office) were established; new funding instruments were developed (most notably the R&D Tax Incentive and the Sector Innovation Fund) or rechannelled (THRIP, Innovation Fund); and significant investments were made to strengthen the knowledge productive and human resources development capacity of South African universities through the funding of 16 CoEs and more than 200 research chairs. In addition, a number of field-specific strategies to support science and knowledge production were developed and implemented; five grand challenges were initiated, funded and implemented; and a number of technology missions were developed, refined and funded. This leads us to our first conclusion:

The Department of Science and Technology (DST) and other departments and agencies have in broad terms delivered on what the NRDS and TYIP – and by extension the 1996 White Paper on Science and Technology – identified as the strategic interventions to strengthen and transform the STI system.

It is important though, to emphasise that this positive assessment pertains to what one can refer to as the 'deliverables' of the NRDS and TYIP; that is, to the enabling mechanisms and programmes that needed to be put in place to strengthen and transform the STI system. It is not as yet an assessment of whether these new initiatives have produced the positive changes and impact as envisaged. This requires an assessment of outcomes and impact at the individual strategy or intervention level which is addressed in our second question.

2. To what extent have the subsidiary strategies and interventions referenced in the NRDS and TYIP produced the outcomes and achievements as anticipated?

Our response to the second question is a differentiated one. Each of the individual strategies and interventions has its own strategic objectives and outcomes, as well as its own theory of change about how to achieve these objectives and outcomes. In the table below, we present a summary assessment of the outcomes and achievements of each strategy/intervention. This summary assessment is based on our detailed reviews of each, found in Volume 5 of the report. Our assessment used the following colour coding.[4]

- To a large extent achieved
- Poorly achieved
- Achieved to a moderate extent
- Not possible to make a judgement

Initiatives/ strategy/ legislation/ funding instrument	Strategic objectives	Assessment of achievement
Intellectual Property Legislation	Protect our IP	
	Utilise and commercialise IP	
	Reduce technology balance of payments	
	Protect IK and IKS	
R&D Tax Incentive	Develop and gazette the necessary legislation to support the scheme	
	Develop the application process and accept applications	
	Undertake pre-R&D review/screening and approval	
	Undertake post-R&D review and approval of funds	
DST/NRF Centres of Excellence Programme	Assessment of key performance areas of research, capacity building and knowledge brokerage	
South African Research Chairs Initiative	Assessment of key performance areas of research, capacity building and knowledge brokerage	
Astronomy Strategy	Promote globally competitive research and innovation	
	Enhance strategic international engagements	
	Establish and maintain research infrastructure and platforms	
Palaeosciences Strategy	Transform the minds of South Africans	
	Support the country's universities	
	Enhance the capacity of museums	
	Ensure that South Africa's palaeosciences heritage is well managed	
Marine and Antarctic Sciences[5]		
Indigenous Knowledge Systems	Create an institutional framework for IKS	
	Establish funding for IKS	
	Develop policy and legislative regulatory framework to support IKS	
	Develop IKS human resource capacity	
	Create an information and research infrastructure for IKS	

4 We have excluded the Innovation Fund (which has ceased) from this summary table. Given the very complicated history of the TIA and our discussion of this in detail in Volume 5, we have also not attempted a summary assessment here. The BLUE assessment means that we could not make a definitive assessment because of a lack of evidence or because of inadequate conceptualisation of expected outcomes.

5 A summative assessment of the implementation of MARS was not conducted for this review, primarily because at the time of undertaking the review, the implementation plan had not been formally approved by the Minister, and many of the targets in the plan extend beyond 2019.

Initiatives/ strategy/ legislation/ funding instrument	Strategic objectives	Assessment of achievement
Advanced Manufacturing Technology Strategies	Focus on priority sectors which have the greatest potential for supporting relevant goals contained in the Integrated Manufacturing Strategy and the NRDS	
	Establish the AMTS and the Implementation Unit	
	Stimulate R&D within private firms	
	New knowledge networks to foster innovation	
	Supply of skilled labour	
	Supply of technology infrastructure	
	Provision of sufficient financial resources	
Information and Communication Technologies	Establish and maintain an effective research infrastructure	
	Foster vibrant international cooperation	
	Provide ICT policy, institutional and other support	
	Adequately resource the ICT R&D and innovation system	
National Nanotechnology Strategy	Support long-term nanoscience research	
	Support creation of new and novel nanotechnology-based devices	
	Develop human resources and infrastructure to support nanotechnology development	
	Stimulate new developments in technology missions	
Bio-Economy Grand Challenge	Strengthen agricultural biosciences innovation to ensure food security, enhance nutrition and improve health, enable job creation through expansion and intensification of sustainable agricultural production and processing	
	Health: Support and strengthen the country's local research, development and innovation (RDI) capabilities to manufacture active pharmaceutical ingredients, vaccines, biopharmaceuticals, diagnostics and medical devices to address the disease burden while ensuring security of supply of essential therapeutics and prophylactics	
	Industry and environment: Prioritise and support RDI in biological processes for the production of goods and services, while enhancing water and waste to support the green economy	
Space Science and Technology Grand Challenge	Establish the National Space Agency	
	A growing satellite industry	
	A range of innovations in space sciences, earth observation, communications, navigation and engineering	
Energy Security Grand Challenge	Renewable energy to form 5% of energy use	
	25% share of the global hydrogen infrastructure and fuel cell market with novel PGM catalysts	
	Demonstrated at pilot-scale the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source	
	A well-articulated energy efficiency programme and per capita energy demand reduced by 30%	
	Ensure universal access to affordable, safe, clean and reliable energy	

Initiatives/ strategy/ legislation/ funding instrument	Strategic objectives	Assessment of achievement
Global Change Grand Challenge[6]	The development of an ambitious and comprehensive 10-year Global Change Science Plan for the broader National System of Innovation	
	A complementary 10-year foresight and roadmap for innovation in adaptation technologies (with a focus on adaptation technologies related to climate change and its associated impacts)	
	Introduction of enabling governance and management arrangements that would support co-ordination with the National System of Innovation to implement the Grand Challenge	
	A specific HCD plan for the Global Change area which is informed by the overall Science, Engineering, and Technology Human Capital Development Strategy	
	An integrated and consolidated programme for reducing the 'knowledge chasm' between research and action and to build the science-policy interface	
	The need to build large-scale integrative flagship global change research programmes that can mobilise the research community	
	The need for South Africa to identify opportunities for co-operation and alignment with continental and global efforts	
	The introduction of a monitoring framework to support planning and reflection on the contribution of the Global Change grand challenge to science and technology, economic development, and environmental sustainability goals	
	Support enhanced information dissemination, exchange and collaboration within the research community as well as between the research community, policy and decision-makers, and society	
	The need for investments in research infrastructure and earth observations for the success of the Global Change Grand Challenge	
Human and Social Dynamics Grand Challenge		

Our assessment of the extent to which individual strategies and interventions produced the anticipated outcomes is, unsurprisingly, mixed. Some of the strategies (especially the interventions around new legislation, HCD and the science missions) generally produced more positive results. Other strategies (including the grand challenges) produced more mixed results. In our discussions of the 'successes' and 'failures' of individual strategies in the Main Report we identify the critical success factors (such as adherence to good practice in strategy design, clarity on locus of agency and ownership, proper implementation and project management, and adequate resourcing). We also discuss why some of the strategies have not produced the expected positive outcomes as anticipated (poor initial conceptualisation and design, poor management and intermittent implementation, lack of sufficient funding, lack of coordination where agency is split across different departments, inadequate monitoring and evaluation and so on).

6 Our assessment of the implementation of the GCGC is based on the ASSAf 2016 *Mid-Term Review of the DST Global Change Grand Challenge*, which assesses implementation of the 10 key action points of the GCGC. The ASSAf review utilises the following rating scheme: GREEN = Achieved; AMBER = Ongoing and RED = Not achieved.

II. DOMAIN-SPECIFIC ASSESSMENTS OF STRATEGIES AND INTERVENTIONS

Human Resources for Science and Technology

There are two key imperatives with regard to Human Capital Development in the STI system: to grow and expand the human resources base for S&T, and to transform the human resource base to become more inclusive of (South African) black and women academics and scientists. Although these two imperatives are not necessarily mutually exclusive, specific strategies to achieve the goals of growth and transformation can produce tensions and, in fact, counteract one another.

The challenges related to expanding and transforming the human resource base for S&T are not new. These challenges were recognised in the 1996 White Paper and are re-iterated in the 2019 White Paper on Science, Technology and Innovation. They are also mentioned in some detail in the NRDS (the reference to the 'frozen demographics') and TYIP. Our reviews of the NRDS and TYIP have shown that these strategic frameworks and subsidiary strategies (e.g. the CoE and SARChI programmes, various science awareness strategies such as the Youth into Science Strategy, as well as references to increasing the international flow of highly skilled people to South Africa through increased collaboration with African countries) are based on three common strategies to achieve the end-goal of increasing the human capital base: (1) to attract local talent to science (especially the science, engineering and technology fields) through science awareness interventions; (2) to retain local talent through the reduction of attrition and drop-out over the course of the academic pipeline, (from undergraduate to doctoral degrees) as well as subsequent (early careers) of academics and scientists; and (3) to attract foreign talent through various internationalisation strategies.

We discuss each of these strategies in some detail in our Main Report and assess the extent to which they have been successful. In brief, the evidence shows (1) that South Africa has not been very successful in attracting local talent to science (mostly because of structural problems in the schooling system); (2) that we have made some progress in reducing attrition and drop-out rates in recent years, but the problem remains a big challenge; and (3) that we have been very successful – especially at the doctoral level – in attracting foreign talent to the country. Unfortunately, as we point out, the recently released NRF funding policy does not make provision for adequate support to foreign students. We argue that this is a short-sighted development that may impact negatively on the gains in doctoral enrolments, which have been witnessed in recent years.

With regard to the transformation imperative, recent studies conducted by the Centre for Research on Evaluation, Science and Technology (CREST) have shown that the trends towards a transformed STI system – especially with regard to race – are now well-established. The picture with regard to gender is slightly more complicated as women's participation in the science system has increased significantly in some areas (e.g. in benefitting from NRF funding or in enrolments and graduations at university), but less so in other areas (such as contribution to scholarly publication). In addition, and not surprisingly, we have found differences in the 'transformation rates' of blacks and women according to age, rank, scientific field and discipline, and institution. However, what is not being investigated in any depth is how these trends are exhibited within individual institutions (universities, science councils and national facilities). Neither, as far as we are aware, has there been any assessment of how the different funding instruments of the NRF, Medical Research Council and the Water Research Commission, as well as other interventions aimed at establishing a more inclusive higher education and STI system, have contributed to the trends that we witness.

Recommendation 1:
An integrated and updated human resources strategy for S&T should be developed and implemented

The omission of a dedicated human resources strategy for S&T in the NRDS, and especially the TYIP, was in our view an oversight. Even though various initiatives were being planned and implemented, none of these were driven directly by the DST. With many stakeholders operating in this space, it was even more important that a coordinated and dedicated strategy for the science system should have been developed. The need for an HRD strategy had already been raised in the White Paper of 1996, in which specific reference was made to the fact that the then Department of Arts, Culture, Science and Technology (DACST) had been assigned the responsibility of "bringing the perspective of S&T to each of these programmes" (DACST, 1996: 38). It was only 13 years later that this was given effect when, in the revised version of the national HRD Strategy (2009), a clear division of labour between DST and the Department of Higher Education and Training (DHET) regarding strategies and programmes related to HRD was made. In 2016, the DST published its own strategy: The Human Capital Development Strategy for Research, Innovation and Scholarship. In our discussion of this strategy, we pointed out that it is a much improved strategy (compared to the HRD Strategy of 2009) but that it still requires further refinement and updating (especially of targets and indicators). Our recommendation thus is that a revised human resources strategy for S&T be developed. Such a revised a strategy must also ensure proper alignment with other existing strategies (such as the University Capacity Development Programme at DHET and the new funding policy of the NRF). This strategy must also align with the system-wide M&E framework proposed below (Section IV) so as to ensure appropriate monitoring and evaluation of the strategy in the future.

Science and Knowledge Generation: Science Missions

The core narrative related to the advancement of science in both the NRDS and TYIP is grounded in the geographic and historical advantage that South Africa has in a number of scientific fields. The underlying premise is simple: invest in and nourish and expand those scientific fields where South Africa has a comparative strength in terms of human resources, accumulated knowledge and scientific infrastructure. As such, both documents identified fields such as astronomy, palaeoscience, indigenous knowledge systems, biodiversity, infectious diseases, deep mining and other 'strong' fields for specific attention. The most explicit set of interventions were reserved for astronomy, palaeoscience, biodiversity (environmental sciences including marine and antarctic research and climate change), and IKS. Our review has shown that the specific focus on these fields has produced demonstrable gains in scientific knowledge output, human resource capabilities and infrastructure.

The initial formulation of the strategies for the four **science domains** included in the NRDS, focused on developing these fields into world-class science domains as well as developing the future R&D capacity in these fields. The focus was on basic science founded on our geographic and accumulative knowledge advantage. However, the subsequent developmental trajectories for each of these four fields shows that it would be more appropriate to describe these as **science missions**, which increasingly incorporated other features under their remit. Each of these four scientific domains – in varying degrees – involved the establishment of new research centres (including CoEs) and research chairs, investment in building new and strengthening existing infrastructure (e.g. new telescopes, the Agulhas II research vessel), and the development of new technologies. This invariably led to the involvement of multiple agencies and stakeholders outside the science sector (various government departments, non-governmental organisations, museums, etc.), which in turn required increasing cross-departmental coordination of effort. In addition, under the all-pervasive regime of new public management and the imperative for science to address socio-economic goals (as captured in the Sustainable Development Goals), all of these 'science missions' are increasingly required to contribute to innovation and socio-economic outcomes.

In summary, what started out as an intent to promote world-class science in these fields, over the years morphed into science-led missions with an increasing focus on technology development and commercialisation to produce socio-economic outcomes. This does not mean that the original intent of supporting excellence

7 Stokes D. 1997. *Pasteur's Quadrant – Basic Science and Technological Innovation*. Brookings Institution Press.

in science (and high level skills development) has been discarded. But it does mark a clear shift towards what Stokes[7] would call 'use-inspired' basic research, or what others have referred to as 'strategic research'. Our reviews of the science missions have raised at least three key issues:

1. The sustainability of the current financing levels for these science missions going forward;
2. The question of differentiation of purpose and mandate in the science system; and
3. Whether the science mission approach can be applied more generally across other 'strategic' scientific fields.

As a 'counterbalance' to the increasing 'appropriation' of scientific disciplines into science and innovation missions, strategic (SDG-led) research and grand challenges, one also has to reflect on how the basic sciences can be protected and strengthened. This led us in the Main Report to a discussion of the Department of Science and Innovation's recent initiative to establish the South African Basic Sciences Platform. The establishment of this platform is not driven by a traditional defence of basic and fundamental science for the sake of science. It is clear from the framework document that the main rationale for this initiative is found in the necessity of supporting the basic (natural and social) sciences because of their essential role in producing the required human capabilities and scientific knowledge that underpin key technologies, which ultimately results in socio-economic benefits. We concluded that this initiative should be applauded as it sends an important signal to the scientific community that re-affirms the worth and importance of basic science.

As part of the preparation phase for the Basic Sciences Platform, DSI commissioned a series of scientometric studies of the basic science disciplines: first of seven natural sciences fields (biological sciences, geological sciences, chemistry, physics, computer science, mathematics and statistics), and then more recently of six basic social sciences (history, sociology, economics, psychology, philosophy, and political studies). The aim of these scientometric studies was to produce an evidenced-based profile of the strengths and weaknesses of each discipline. Four main dimensions of each field were assessed: (1) NRF investment, (2) capacity and diversity of academic staff, (3) academic pipeline, and (4) research performance. A strength of this approach is not only that the work of the platform will be informed by reliable and recent data about each field, but also that extensive engagements have commenced where the findings and recommendations of these reports have been discussed with key stakeholders in each field.

Recommendation 2:
Expand the range of basic science disciplines to be included in the DSI basic sciences platform

A glaring omission in the current list of basic science disciplines is the exclusion of basic health sciences. We strongly recommend that the DSI,in cooperation with the Department of Health and the MRC, identifies these disciplines (such as virology, genetics and heredity, cardiovascular and respiratory diseases, physiology, immunology and pathology) for inclusion in the platform, and commissions comprehensive scientometric studies of these fields as well.

From technology strategies to enabling and cross-cutting technology platforms

Four technology strategies – biotechnology, advanced manufacturing, resource-based technologies and ICT – were explicitly identified in the NRDS for support and development. Although the NRDS made reference to 'technology for poverty reduction', as far as we could establish no separate strategy was developed. Nevertheless, it was defined as a DSI programme and substantial monies were allocated to it: R132.4 million between 2009/10 and 2014/15. Owing to changing priorities, this programme eventually evolved into a new programme 'Innovation for inclusive development', which since 2015 has received R126.9 million in funding. The National Biotechnology Strategy (2001), which preceded the NRDS, was further given dedicated attention and funding, and would eventually become an integral part of the Bio-economy (Farmer to Pharma) Grand Challenge. As far as the other three technologies (advanced manufacturing, ICT and nanotechnology) are concerned, our review shows that each of these subsequently followed a very different developmental trajectory. At the time that the TYIP was published, the focus had shifted from a discussion of these technologies as clearly delineated and separate technology missions, to an emphasis on their role as cross-cutting enablers (together with HCD and knowledge infrastructure) for the five grand challenges. The shift in the narrative from the NRDS to the TYIP does not necessarily signify a shift in emphasis or importance. But it does demonstrate

the difference between a more 'technocratic' – even 'linear' – approach to the role of technology in development (NRDS) to an approach where technology serves the demands for inclusive development in society (TYIP and the 2019 White Paper). This shift is analogous to the shift from defining technology in terms of clearly demarcated 'technology push-missions' to seeing technology as a cross-cutting and enabling platform in addressing societal challenges.

Recommendation 3:
We recommend that the DSI (and partners) undertake a fundamental re-assessment of the current technology programmes

The original objectives of the technology-related strategies in the NRDS and TYIP – to contribute towards the transition to a knowledge-based economy, to improve the sector's competitiveness through advanced manufacturing and innovation, and to leverage resource-based industries – are still valid. What has changed over time is the introduction of new initiatives, such as in fluoride-based electrolytes, titanium powder, additive manufacturing and advanced materials. Technology changes are fast-moving and are often linked to new challenges resulting from fundamental shifts in social dynamics. We hence believe that it is prudent for the DSI to revisit its current portfolio of technology programmes (in the light of recent global developments as well as the recommendations of the Research Foresight exercise) going forward.

Recommendation 4:
Digital skills and knowledge development

We recommend that the DST cyber infrastructure project be enhanced in four important ways: (1) a programme of R&D investment in universities and SET institutions that addresses the wider digital innovation agenda, focused on advancing new digital technology fields (such as artificial intelligence and social data analytics), as well as on digital applications in public education (e.g. digital applications in mathematics and science teaching), public health, digital government and nanotechnology to name a few; (2) a programme of investment in skills for digital R&D and innovation; (3) explicit attention to the gender, youth and other social dimensions of R&D and innovation for the digital economy/society; and (4) encouraging the design and use of applications of dynamic software in mathematics, science and technology subjects in primary and secondary schools. The DSI (and relevant departments) should foster and invest in large-scale research networks for digital innovation that include the universities, science institutions, private sector, public sector, and proto-innovation entities such as technology hubs, makerspaces and other digital innovation contributors, ensuring that these networks include geographic areas with low R&D funding. In this effort, attention must be given to investments that promote women in science, and science for women, in the digital innovation sphere.

Recommendation 5:
Nanotechnology: Strengthening areas of research, development and innovation

It is recommended that the current NIC programme be continued, but in a modified format, with an extended focus on research translation and commercialisation. It is also recommended that a review be commissioned to investigate the feasibility of continuing with two separate NICs (at the Council for Scientific and Industrial Research and Mintek). Such a review should address the question of whether better oversight and coordination of the national research agenda can be achieved; for example, through the development of a new roadmap of research priorities and opportunities to avoid duplication, enhance collaboration, and act as a focal point for the development of the skills required to optimise achievement of commercial outcomes. In addition, there are areas of relevance and potential impact not being addressed across the existing NICs, such as energy generation and storage, and food and health (e.g. therapeutics, treatment), although many of these are being addressed at other institutions across the country. A technology roadmap which provides granular detail is required to ensure research at every relevant institution is being directed appropriately. This applies equally to the commercialisation of research outputs, and could be achieved through high level direction from government through the alignment with new societal challenges.

The Grand Challenges

The notion of a 'grand challenge' appears in the TYIP in 2008. The stated purpose of introducing these grand challenges was that they would "address an array of social, economic, political, scientific, and technological benefits" and were "designed to stimulate multidisciplinary thinking and to challenge our country's researchers to answer existing questions, create new disciplines and develop new technologies" (DST, 2008: viii). Each of the grand challenges is outlined in a narrative, the details and scope of which vary quite widely, but in each case a set of "outcomes" plus some indicators were stated.

Even a cursory inspection of the five grand challenges as outlined in the TYIP would show that most of them do not correspond to the notion of a 'grand societal challenge' as outlined in more recent OECD documents and strategies. The seven societal challenges included in the European Union's Research and Innovation programme, Horizon 2020, all refer very specifically to problems and deficiencies that are present and grounded in society: in healthcare (including the burden of disease), food security (such as hunger and malnutrition), safe and clean energy, the problems of pollution and high carbon-emissions, problems related to refugees and migration, lack of social cohesion, poverty, inequality, etc. These are not scientific or technological problems – they are human problems. What is distinctive about the OECD approach since 2008, is that the societal challenges (or set of complex problems) are taken as the starting point for the development of S&T policy and strategy. Whereas in traditional S&T missions, strategies were developed from the perspective of the science base or technological capabilities, 'directionality' in current STI policies that has its origins in society and our diagnosis of key societal challenges.

Despite being grouped together under the rubric of 'grand challenges', the individual grand challenges in the TYIP are in fact not very similar. Close inspection shows rather big differences in the underlying premises and logic. In a nutshell, we argue (1) that the grand challenges of global change and energy security – and to a lesser extent bio-economy – most correspond to current notions of 'societal challenges'; (2) that the space science and technology grand challenge is better understood as an expanded S&T mission; and (3) that the thinking behind the human and social dynamics grand challenge was flawed from the outset and conflated a substantive focus (on social issues) with the ideal of giving expression to the transversal nature of social, economic, legal and ethical dimensions in most science and technological interventions.

Recommendation 6:
The DSI should pursue the notion of 'grand societal challenges' as a framing principle for the development of the high-level interventions in the next decadal plan

We believe that recent scholarship in STI policy design has shown that such an approach is justified where countries (perhaps more so developing countries) are faced with complex, persistent and seemingly intractable societal problems. The caveat to this recommendation is that the conceptualisation and design of such grand challenges should adopt the learnings from recent reviews of similar instruments elsewhere. The current global (climate) change and energy security grand challenges should be included in the redesign of the societal challenges. The current bio-economy grand challenge should be reconceptualised with a focus on at least food security (a possible new grand challenge) and burden of disease (an essential addition to the grand challenges given current experiences with the coronavirus pandemic).

Recommendation 7:
Investigate the establishment of clusters or platforms of research chairs around common societal challenges

There are currently more than 200 active research chairs. With some exceptions, research chairs have been awarded on a competitive basis with little directionality from the NRF. But it is also clear that 'clusters' of chairs have emerged over time. As far as we know there is currently no mechanism to ensure that knowledge generated by chairs in such clusters are shared in a systematic fashion – either with each other and/or with other stakeholders in governments and industry. We therefore recommend that an investigation be undertaken (which would include all the chairs and relevant stakeholders) into the feasibility of establishing a number of **Research Chair Clusters** in those areas which correspond to the societal challenges that South Africa faces currently and in the future.

System Governance and Policy Coordination

There is a strong consensus across all previous system-wide reviews about the key challenges in the STI system around governance, institutional differentiation and coordination. The fact is that nearly every review identifies the same problems – lack of an integrated policy framework; lack of vertical and horizontal coordination across departments and public research agencies; lack of a singular science vote; lack of central and independent science advisory bodies; and inadequate evidence on the system that would allow for better monitoring, evaluation and planning (including future tools and methodologies). It is worth noting that the 2019 White Paper agrees with much of this assessment. Our review shows that while there has been progress in some instances (as with the Strategic Management Model), these are deemed to have only had limited effect. In other cases, some recommendations have been taken up (such as the institutionalisation of M&E in the system as advocated in the 2019 White Paper).

But the fact that so many (similar) recommendations pertaining to improved policy coordination and strengthening the governance of the STI system have been made repeatedly and have not been enacted upon, suggests deeper and recalcitrant obstacles to uptake. It seems as if the new White Paper has 'given up' on going the route of legislation, and instead reverted to other instruments: using (sector) funding to enforce coordination across departments, softer mechanisms (such as memoranda of agreement, a new policy framework and setting up committees), and M&E as a tool to ensure compliance with such new measures.

Recommendation 8:
We strongly re-affirm the findings of previous reviews regarding the necessity of a strong, central STI governance body such as the proposed ministerial-level STI structure

Previous attempts at achieving a similar structure have come to nought which suggests that STI issues do not seem to have the same high-level traction when compared to other national priorities. Ironically, the current experience around the state's response to the Covid-19 crisis may support future attempts to establish such a central structure. It is clear, not only in South Africa, that the pandemic has re-legitimised the value of and trust in science, facts and evidence. The re-affirmation of the necessity of a strong science base in a country to deal with societal challenges may well be a sufficient trigger to galvanise Cabinet to approve the establishment of such a ministerial-level structure.

Recommendation 9:
We re-affirm previous recommendations regarding the necessity of policy coordination, and hence support the proposed establishment of a national STI plenary

Although we support this recommendation – as phrased in the new White Paper – we would also recommend that some essential preparatory investigation is done on the mandate of such a plenary and how it will function most effectively. If such a plenary is in fact tasked with addressing the challenge of policy coordination across sectors and government departments, it will have to be given the required authority to do so. If not, it will simply become yet another informal forum for the exchange of ideas of which the system already has many examples.

Recommendation 10:
With regard to the establishment of three policy nexuses to improve implementation of STI-related interventions across all government departments, we suggest that this proposal be subjected to further scrutiny and investigation

The proposal to establish three policy nexuses has its origins in the 2012 Ministerial Review of the Science, Technology and Innovation Landscape and is included in the 2019 White Paper. According to this proposal, three nexuses would be established to harmonise and coordinate implementation plans in education and skills development, the economy, and the "social" (sic). It is not clear how these specific nexuses were arrived at, but we believe that the uncritical implementation of this proposal might in fact be counterproductive as it could end up creating more silos in implementation and less coordination across

sectors and government departments. How, for example, will cross-cutting issues between education, the economy and society be addressed under this model? And, how will the establishment of these nexuses align with initiatives to expand and deepen the framework of societal challenges?

Financing of Research and Innovation

All previous system-wide reviews recognised that the South African STI system is under-financed, that public expenditure on R&D is insufficient, and that the contribution of the business sector to R&D (BERD) has declined to alarming proportions. The declining trend of BERD has been recognised by the South African government. The causes of this trend are also reasonably well understood and include the partial demise of several large companies which were responsible for the bulk of BERD (e.g. Anglo American and Eskom), the movement of local R&D to other countries (De Beers and others), and the closure of the Pebble Bed Modular Reactor. The DST has adopted a broad set of instruments to deal with this problem, including the introduction of the R&D Tax Incentive, the establishment of the TIA, and the direct funding of BERD in certain sectors such as energy, biotechnology and pharmaceuticals. Some of these recommendations have been adopted by the new White Paper, which lists four policy intents related to financing: (1) increase funding to the NSI, with a focus on increasing business and foreign investment in STI; (2) encourage provincial and local governments to invest more in STI as part of their development strategies; (3) improve the allocation of public funding for STI, and the coordination of public investment, to ensure that government's STI priorities are appropriately funded; and (4) enhance the efficiency of funding in the NSI.

Given the dire situation of the economy and the real possibility that the first (and even the second) intent (to increase GERD/GDP to 1.5%) will not materialise, it is perhaps prudent to focus on strategies to improve coordination of current investments, as well as ways to enhance the efficiency of existing funding instruments in the NSI. Against this background, our recommendations regarding financing are thus skewed towards interventions that will produce greater coordination and efficiency gains.

Recommendation 11:
Institutionalise private sector cooperation and agreement when designing interventions to increase financing of innovation

For initiatives which involve significant private sector cooperation and agreement, prior consultation with private firms on the details of implementation is essential. We formulate this as a general recommendation specifically based on our review of the R&D Tax Incentive. Although there was some initial consultation, this was insufficient to counter the initial suspicion of, and resistance to, the scheme. Moreover, such initiatives must be accompanied by a significant public awareness campaign. In many cases, it appears that the target beneficiaries were unaware of the scheme, how it operates and how it could assist them.

Recommendation 12:
Continuance and strengthening of the R&D Tax Incentive scheme

Raising new revenue from National Treasury, or persuading it to give up existing tax revenue, will be almost impossible in the next five-to-ten years. The DSI should therefore take great care not to relinquish its tax incentive despite recent negative reviews, but work much harder to improve the impact of the scheme over the next period. Our review showed that although the scheme has not induced the necessary behavioural change in the private sector (increase in R&D expenditure), it has been implemented quite successfully from an administrative perspective, despite some initial teething problems. In particular, it is noted that the scheme was not shaped by a dedicated strategy; it relied heavily on the agreement of another government department; and it lacked, at least initially, a clear set of outcome measures. As a result, it took time to find a modus operandi which could meet the needs of all its participants.

Recommendation 13:
An appropriate quality M&E framework needs to be implemented to ensure that the DHET publication funding system adheres to good practice in responsible research

Studies conducted by CREST (commissioned both by the Academy of Science of South Africa and the DHET) have revealed that the current publication funding system (which disburses more than R2.4 billion annually to the universities) has been hugely effective in stimulating growth and productivity among university academics. Unfortunately, the system has also led to various unethical and fraudulent publication practices. In two recent studies, we have unearthed compelling evidence of significant abuse and gaming of the subsidy framework through publications in predatory journals, excessive claims for publication outputs, clear and evident gaming of subsidies linked to conference proceedings, as well as increasing evidence of unethical behaviour by journal editors. The aim of the implementation of the proposed framework would be to assess and re-affirm both the quality and integrity of publications by South African academics.

III. STRATEGY DESIGN

Our formative assessment of the **NRDS** concluded that insufficient attention was given to developing a well-constructed and explicit theory of change for the strategy: the implicit theory of change is neither self-evident nor coherent. We also concluded that the description of outcome statements, setting of targets and technical description of indicators fell short of good practice in intervention design. With regard to the **TYIP**, we concluded that the plan is weak as far as a theory of change is concerned. In addition, the core narrative of the TYIP is built around the imperatives of achieving a knowledge economy, but no attempt is made to show how the TYIP builds on the NRDS and gives expression to core challenges identified there. The focus on the five grand challenges as the means whereby South Africa would address its socio-economic problems was deemed to be a positive feature of the TYIP. However, the 'construction' and 'presentation' of the five grand challenges are uneven and do not conform to the standard logic of what grand challenges are. In addition, we also concluded that the M&E elements of the TYIP were lacking.

Our reviews of the subsidiary strategies and interventions revealed many cases where the 'rules' of good practice in strategy design were not followed. Good practice in strategy design dictates that the formulation of a strategy (with clear goals, objectives, an explicit theory of change and well-defined outcome statements) should be followed by a clear and concrete implementation plan. Such a plan is an operational version of a strategy, and specifies clearly how the strategy will be implemented: the resources that are required, the actors that will deliver the strategy within specified timelines, clearly stated deliverables, targets, and explicit performance and outcome measures or indicators. In an ideal world, a strategy is followed fairly quickly by an implementation plan. Reconstructed timelines for many strategies reveal the same 'fault lines': (1) long delays in moving from formulating a strategy to an implementation plan; (2) in some cases, we could not identify or locate an implementation plan (although occasionally we found a PowerPoint of an implementation plan); and (3) in more complex cases (such as marine and Antarctic sciences), the timeline shows a lack of a clear and linear path from strategy to implementation (and in some cases to M&E).

It is also important to emphasise that our review reveals that some strategies and interventions were implemented despite the absence of an explicit (and updated) implementation plan (which we established through an analysis of the annual expenditures and disbursements of the DST, Department of Trade and Industry and other agencies). We also found evidence that strategies and implementation plans were often rewritten (with changes in the formulation of strategic objectives, outcome areas and indicators) as time progressed. This is not surprising and can even be described as 'good' project management as interventions sometimes need to adjust to changing circumstances. However, even in such cases, good practice in strategy design would dictate that fundamental revisions in strategic goal and objective statements should be informed by regular performance monitoring and evaluation studies. It is not clear to us that this was always the case.

Recommendation 14:
Institutionalise good practice in appropriate strategy design and implementation

In the formulation of future strategies and implementation plans, good practice in intervention design needs to be adhered to. Within the present environment of fiscal constraints, policy objectives without allocated budgets – even if these have to be obtained through the re-direction of existing allocations – will be meaningless. Full attention needs to be given to how each policy objective will be funded and resourced. As far as possible, focus should be placed on objectives which have a linear and single-department theory of change. Initiatives which require significant inter-departmental agreement and cooperation, and particularly negotiations on areas of control, are complex to navigate and have a high rate of failure. Impact areas within which the variables have a non-recursive relationship (in other words, bidirectional causality) are similarly complex, and sustainable change will only be evident over long periods of time (such as the impact of IP legislation on the output of technology-intensive industry). Our formative assessment has revealed many examples of poor formulation of strategic goals and objective statements, as well as widespread confusion between goals and objectives and between outputs and outcomes. It is strongly recommended that all future strategies and plans devote dedicated attention to explicit theories of change, with clearly defined short- and medium-term objectives and outcomes.

Recommendation 15:
The design of new strategies and plans must meet the criteria of feasibility and risk assessment

Key requirements of strategy design pertaining to the implementability and feasibility of an intervention need to be met. This implies that more attention should be given to agency (locus of responsibility) and resource estimates (budgets and infrastructure) and timeframes. In addition, a well-designed strategy must make reference to possible risk factors that can constrain or even invalidate its proper implementation.

Recommendation 16:
Strategic plans must adhere to good practice in the setting of targets and the construction of appropriate performance and outcome indicators

We have commented throughout our review, but especially in our summative assessment of the NRDS and TYIP, on the many instances of inappropriate and unrealistic target-setting. Such practice means that the authors of these strategies did not search properly for supporting evidence in setting appropriate and realistic targets. In addition, insufficient attention is given to the distinction between qualitative and quantitative (statistical) indicators, as well as to the availability of data to populate indicators.

IV. MONITORING, EVALUATION AND LEARNING

Our review of the NRDS and TYIP and the associated subsidiary strategies and interventions discovered many shortcomings at all levels of the STI system in terms of M&E expertise. Although there is some evidence of improvement over time, it is clear that M&E capabilities in terms of outcome-mapping and target-setting, indicator construction, performance measurement, use of appropriate data sources and impact evaluation remains below par. However, in fairness, our assessment of the state of M&E in the domain of STI needs to be qualified when read against the background of the progressive institutionalisation of M&E in South Africa since 1994.

At the time that the NRDS was published in 2002, there was as yet no formal structure in place in the public sector that would guide the design of policies and strategies regarding performance measurement or monitoring. It would only be in 2005 when the Government-wide Monitoring and Evaluation Framework was adopted, that guidelines were published to assist government departments and public sector agencies with M&E in a more systematic manner. It is worth noting that DACST led the way in 1998 by institutionalising

performance measurement for the science councils using the balanced scorecard methodology. Furthermore, Annual Performance Plans (which include statements of outputs, targets and indicators) were required as of 2000.

By the time that the TYIP was published in 2008, things had changed fundamentally. M&E imperatives and requirements were much more entrenched in the public sector, and a very 'pervasive' and standardised form of reporting on M&E had become the norm. In the recent past, the nature and scope of M&E demands have become even more comprehensive. Significantly, with the publication of the National Evaluation Policy Framework in 2011 a major shift occurred. Whereas the pre-2011 era can be described as being predominantly focused on performance monitoring and compliance reporting, the emphasis now is on reporting on outcomes and impacts (in the terminology of the Work Bank – on results). As a corollary to this, government departments are now also required to regularly conduct (external) impact evaluations of their major interventions.

In a recent report submitted to the National Advisory Council on Innovation (NACI), SciSTIP identified more than 100 evaluation studies and reviews that pertain to the STI system that have been undertaken since 1998. Our conclusion in this report identified three problem areas: (1) there has been insufficient coordination within the STI system in the commissioning and execution of evaluation and review studies, with the result that (2) there has not been any systematic learning and uptake of these results to inform STI policy, strategy and planning, which in turn can be attributed to (3) a general lack of capacity and technical expertise in policy and strategy design and analysis.

Recommendation 17:
Implement a system-wide monitoring and evaluation framework for the STI system

An explicit monitoring, evaluation and learning framework needs to be implemented for STI in South Africa. In a recent report to NACI, SciSTIP presented the broad outlines of such a framework. Our first recommendation is that this framework is adopted and implemented as a system-wide M&E framework for the STI system.

Recommendation 18:
Establish a national data centre (or 'observatory') on the South African STI system

Various initiatives have been attempted over the past decade to establish a national (virtual) centre that would combine and integrate, all relevant data on key components of the STI system. These initiatives have thus far come to nought. Data continue to be housed at different institutions: on research funding and expenditure (the Centre for Science, Technology and Innovation Indicators and various government departments); human resources for S&T (DHET and its Higher Education Management Information System); scientific publications (CREST); agency funding (the NRF, MRC, WRC, Agricultural Research Council and others); and IP indicators (the National Intellectual Property Management Office). Various countries have established national observatories for STI, or at least national centres where such data is housed centrally and made available for analysis and research. Typically, such observatories are not housed within government departments or agencies, but either established as independent agencies (e.g. OST in France) or linked to one or more universities (e.g. the Centre for R&D Monitoring at the University of Leuven in Belgium). We recommend that serious consideration be given to the establishment of such a data centre or observatory, especially if Recommendation 18 above is accepted. The implementation of a system-wide M&E framework will require that an integrated science and innovation data facility is established.

Recommendation 19:
Institutionalise (continuous) professional development in research evaluation

There are currently initiatives afoot in the M&E sector in South Africa to strengthen and institutionalise a standard set of M&E competencies for all professionals who work in this area. This initiative, which is driven by the South African Monitoring and Evaluation Association, aims to develop a certificated course

to ensure that all M&E professionals in the public sector adhere to international best practice in this field. Our specific recommendation is that this initiative be adopted within the STI system, but also adapted to the specific requirements of monitoring and evaluating the ongoing performance and achievements of STI interventions and programmes. Adopting this approach means that general principles that apply to M&E need to be customised for the specific demands of STI policy reviews and assessment, research programme and institutional evaluations, technology assessment and other STI-specific interventions.

Recommendation 20:
Establish a mechanism to ensure policy learning across the system

Our review has highlighted the fact that STI policy learning has been sub-optimal. The analysis of the NRDS and TYIP revealed examples of (1) repetition of similar findings over time, (2) repetition of recommendations from review to review, and (3) general lack of 'monitoring of uptake and learning'. It is recommended that policy learning is institutionalised in the system with the mandate to conduct regular meta-reviews of all higher education and STI reviews, and to organise policy learning forums with relevant stakeholders in order to ensure more consistent and appropriate uptake and use of system and programme reviews.

V. FURTHER RESEARCH AND REVIEWS

Recommendation 21:
An in-depth scoping and impact assessment study of the existing human resources interventions for S&T should be conducted

There are currently numerous strategies, interventions and funding instruments being managed by the DSI, NRF, DHET, MRC, WRC and other departments and agencies that refer to the need to expand and transform the human resources base for science and innovation in the country. In our assessment, there is still insufficient inter-departmental and inter-agency coordination between these different initiatives. There is also no central database on these interventions and the financial investments that are currently being made in this area. We therefore recommend that (1) a definitive scoping study is undertaken of all of these interventions (including funding instruments); (2) that the results of such a scoping study be used as the point of departure for developing an integrated and transversal strategy for the expansion and transformation of human capital for the NSI; and (3) that a comprehensive impact assessment is undertaken of these initiatives.

Recommendation 22:
Conduct a study into the optimal size and number of the two flagship science programmes

Although the CoE and SARChI programmes have been reviewed by the NRF, we recommend that a more comprehensive study is conducted that goes beyond the past reviews to include questions about the optimal size and shape of these programmes. Such a review, which should be commissioned externally, should address issues such as: whether all CoEs and research chairs should have identical key performance areas (we believe that there are good arguments for a more differentiated approach); and whether there should be a clear pathway for some CoEs to become national institutes and, similarly, for clusters of research chairs to become a national centre or network of excellence. This study should also explore how the CoEs and SARChI chairs could be better linked to other public research institutes in government as well as to R&D units in the industry.

Recommendation 23:
Conduct a systematic evaluation of the socio-developmental benefits of the investment in astronomy

Arguably, astronomy is the success story of the research and innovation system. However, the actual benefit accruing to local communities is more difficult to establish, more so as the Square Kilometre Array (mid- and high-frequency array) that has yet to be constructed, and a lot of astronomy research is conducted remotely rather than primarily using local infrastructure. We therefore recommend that a systematic evaluation be undertaken of the extent to which the investment in astronomy has produced the expected societal and development outcomes.

Recommendation 24:
Conduct a comprehensive review of the implementation and outcomes of the Palaeosciences strategy

Serious consideration should be given to expanding the Centre of Excellence in Palaeosciences to become something akin to a 'national institute' which functions across the entire country. The funds provided by the NRF to the CoE have added much value. Additional and increased funding for a new palaeosciences national institute with a broader mandate would add value to the palaeosciences community and to a broader public audience. Furthermore, a comprehensive review of the activities of the Department of Arts and Culture and the agencies responsible for heritage and museum management (such as the South African Heritage Resources Agency), as well as palaeo-tourism, should be conducted. The evidence suggests that the contribution of the Natural History Museums, and particularly the DAC, towards developing the palaeosciences in South Africa has been disappointing. Currently, the development of human capacity in the palaeosciences has been successful, but without the creation of entry-level positions for palaeoscientists, particularly at museums, the uptake of skilled graduates is lost. Finally, one of the planned interventions outlined in the South African Strategy for the Palaeosciences includes a review of the heritage legislation. Our review of the strategy found that the drafting of the legislation was done without consultation with the palaeosciences community, and that the current legislation severely hampers their research activities. We thus recommend that SAHRA act in consultation with palaeoscientists to ensure that the heritage legislation actively supports the activities of the palaeosciences community.

Recommendation 25:
Conduct an independent review of the Marine and Antarctic sciences strategy

Given the obvious complexities of the Marine and Antarctic Research Strategy as a multi-agency, multi-site set of interventions, we recommend that the DSI, in consultation with the other key stakeholders and implementing agencies, consider commissioning a comprehensive external review of the implementation and short-term achievements of the MARS. The strategy framework is sufficiently detailed to inform such a review.

Recommendation 26:
An independent study should be undertaken on the current grand challenge for space science and technology

Such a study should look into the possibility of it being redesigned as an expanded (with sufficient funding) S&T mission as well as its possible integration with the astronomy/SKA/Meerkat mission.

Recommendation 27:

Undertake an in-depth review of existing funding instruments targeting business and innovation in order to achieve optimal coordination and efficiency

This recommendation is in line with the fourth policy intent around financing in the 2019 White Paper. It is also specifically informed by our review of TIA as well as an analysis of the different funding programmes at DSI and dti. As far as we could establish, there has not been a recent review of the key funding instruments and programmes in innovation and business support, including the Technology and Human Resources for Industry Programme and the Support Programme for Industrial Innovation (at dti) and the different instruments managed by TIA (Technology Innovation Agency).

Recommendation 28:

As a corollary to the previous recommendation, we also recommend that a comprehensive and external review of the mission and strategic objectives of TIA be undertaken

Such a review must revisit the premises for the creation of the TIA. Whatever the outcome of that exercise might be, the mechanisms for selection of funding proposals, the desirability, if at all, of demanding an equity or IP stake, and the mechanisms for project exit, require careful reconsideration. Such a review must appreciate both the complexity and diversity inherent in the Agency. Our recommendation then is for a review that follows an open and exploratory process without any pre-determined set of outcomes in mind.

Recommendation 29:

A study should be conducted to assess the extent and possible synergy between the investments of the universities, funding agencies (NRF, MRC, WRC) and government departments (DHET, Department of Water Affairs and Forestry, Department of Health) in building the next generation of scientists and scholars in the country

Various departments and agencies as well as all the universities in the South African STI system invest significant funds in building the academic and scientific pipeline. This funding includes various bursary and scholarship schemes, as well as grants to post-doctoral fellows, emerging scholars and early career academics to enable them to become established scientists and scholars. We recommend that a study be undertaken (1) to establish the quantum of public investment in this area; and (2) to identify possible areas of duplication as well as synergy for better coordination.

Volume I

STUDY DESIGN, ANALYTICAL FRAMEWORKA ND METHODOLOGY

CHAPTER 1

INTRODUCTION

1.1 Terms of reference for the review

In late 2018, the National Advisory Council on Innovation (NACI) commissioned SciSTIP to undertake a comprehensive review of the 2002 National Research and Development Strategy (NRDS) and the 2008 Ten Year Innovation Plan (TYIP). The purpose of the review was defined in the terms of reference as conducting "a retrospective assessment of the NRDS and TYIP", which were the key instruments used to implement the 1996 White Paper on Science and Technology's broad vision and framework for science, technology and innovation (STI) activities. The ToR noted that aspects of the two policy instruments had already been, or were in the process of being, reviewed by the DST, and that there had been tracking of some indicators, such as those covered in the annual NACI STI Indicator reports. It highlighted, however, that this would be "the first major review of the two policy instruments since their establishment."

The ToR outlined the following dimensions that the review would need to take into account and address:

- The review would need to recognise that the implementation of the two policy instruments (especially the goals or objectives) has straddled the Department of Science and Technology (DST) and other government departments (reflecting the cross-cutting nature of STI).
- The review would have to find a way of identifying, mapping and reflecting on all activities or policy initiatives – both within and outside the purview of the DST – in order to develop a better understanding of the progress or lack thereof in implementing the two policy instruments.
- The conceptualisation and design of the review methodology should view the NRDS and TYIP as distinct but interrelated policy instruments with different objectives. The review methodology should propose a mechanism for dealing with continuities (in terms of time and overlapping activities) and discontinuities, on the one hand. On the other hand, it should take into account that both the NRDS and TYIP consist of main documents and sub-strategies (such as the space strategy, bio-economy strategy, etc.).
- The review would need to provide deeper insights into the dynamics of policy implementation or lack of implementation. The emphasis must be on the lessons learnt, in order to advise on what worked or did not work, to recommend actions to address current policy gaps, and to inform the development of future strategies or plans. The results of the review would find immediate application in the development of the new decadal plan for STI.

The ToR listed the following tasks that needed to be completed under this review:

- Reflect on previous STI reviews focusing on specific aspects of the two policy instruments;
- Conduct quantitative and qualitative analysis of these;
- Clearly identify what has been achieved and not achieved;
- Identify factors that impeded/facilitated achievements;
- Recommend actions to address current shortcomings or barriers; and
- Draw lessons about the implementation of STI policy initiatives to inform future policy development.

Finally, according to the ToR, the study should follow a mixed-method design using both secondary and primary quantitative and qualitative data.

1.2 Overarching review questions and levels of analysis

We interpreted the above expectations and specifications of the ToR into the following overarching questions to guide the review:

1. What were the problems identified that the NRDS and TYIP sought to address?
2. What strategies and interventions did they propose to address these issues?
3. What were they intending to achieve and what outcomes and impact did they anticipate?
4. To what extent and in what way was there continuities and discontinuities between the NRDS and TYIP themselves, and in relation to the associated interventions?
5. To what extent were the proposed interventions implemented and the desired goals and outcomes and impacts achieved?
6. What factors impeded or facilitated implementation and achievement of the desired outcomes?
7. What can we learn about strategy and intervention design and implementation, based on the review of both the NRDS and TYIP and the identified subsidiary strategies and interventions?
8. What recommendations can be made to inform future policy development, strategy and planning design, and implementation?

It was evident from the requirements of the ToR that the review would need to be conducted both at the level of the two strategy documents (NRDS and TYIP) as well as at the level of the 'subsidiary' strategies and interventions referenced (either explicitly or implicitly) in these two documents. Throughout this report we will refer to these as **Level 1** and **Level 2** analyses and the specific details of the focus of these two levels of analysis are discussed in Chapter 3 below.

Furthermore, the review would need to comment on the nature of strategy and intervention design and make recommendations on how this could be improved, and to identify what has been achieved or not achieved at the levels of outcomes and impacts. These distinctions speak to the link between evaluation questions and evaluation purpose (**formative** and **summative** assessments) which we address in Chapter 2 below.

1.3 Distinguishing between policies, interventions, strategies and plans

Policies (national/institutional) are typically high-level normative (and even aspirational) statements of what a country, system or institution aspires to achieve (vision), and more precisely what the desired end-states or goals of the system or institution should be. In order to operationalise the policy, dedicated *interventions* are conceptualised, designed and subsequently implemented in order to produce the achievement of these goals. The internal logic of the design of the intervention and the outcomes it is intended to produce is referred to as the 'theory of change' of the intervention. Interventions can include a wide variety of actions or activities, such as laws, regulations, campaigns, programmes, projects, instruments, incentives or organisational change. *Strategies* are (usually high-level) documents which describe and give coherence to the basket of interventions to be implemented in order to achieve the intended outcomes, effects and impacts. They often contain more detailed and specific goals (long term) and objectives (short to medium term) relating to the policy as a whole or aspects thereof. The adoption of a strategy is ideally followed by an *implementation plan*; that is, a plan that

provides detailed information about the resources that are required to implement the strategy (people, funding, infrastructure, equipment); the scheduling of key activities by designated actors within clear timeframes; the delivery of outputs against targets (milestones); and a clear indication of the expected short-term outcomes and how to assess these (outcome indicators).

In summary, policies, strategies and plans fall on a spectrum of a level of abstraction – from high-level statements of intent (policies and strategies) to concrete plans of action (implementation plans and specific interventions). They also differ in terms of timeframe: from long-term aspirational or visionary statements of impact (e.g. 10 years +) to medium-term (5-10 years) and short-term (less than 5 years) strategies and plans with immediate deliverables and outcomes. Interventions can have short, medium or long-term timeframes.

The 1996 White Paper on S&T and the 2019 White Paper on STI fit the definition of 'policies' as outlined above insofar as they are both high-level and long-term (aspirational) statements. However, as will be seen in Volume 2 (Chapter 1), the content and scope of the NRDS and the TYIP do not fully coincide with the standard distinction between and definitions of a 'strategy' and a 'plan'. For the purposes of this review, we therefore refer to these two documents as *'system-wide strategic frameworks'*. In addition, we refer to the set of 21 subsidiary *'strategies and interventions'* identified for inclusion in this review, which range from single strategy documents (e.g. the Bio-economy Strategy), collections of strategies (those related to the Energy Security Grand Challenge), and programmes (e.g. the Centres of Excellence programme), to funding instruments (e.g. the Innovation Fund), organisations (the Technology Innovation Agency), and initiatives to promote and advance particular scientific fields (e.g. astronomy and the palaeosciences).

STUDY DESIGN AND ANALYTICAL FRAMEWORK

2.1 Components of the review process

There were four major components to the review process. These may be summarised as follows:

- **Preparation:** Developing the review/evaluation design, methodology and analytical framework; Unpacking and summarising the substantive focus of the NRDS and TYIP (problems identified, goals, expected outcomes, and STI domains highlighted), and making explicit the theory of change within each; Identifying and listing indicators explicitly referenced in the NRDS and TYIP; Identifying the subsidiary strategies and interventions to be reviewed, and delegating the individual reviews to members of the team; and Collecting core reference documents and supporting materials pertaining to both the NRDS and TYIP as well as the individual strategies and interventions.

- **Formative and summative assessments of the NRDS and TYIP:** Developing the review questions and template for the formative assessment of the two documents; and Generating available data (to most recent years) for the indicators identified in the two documents (summative assessment).

- **Formative and summative assessments of the individual strategies and interventions:** Designing the review templates to be followed; Writing draft individual strategy reviews; and Circulating draft reviews to critical readers.

- **Integration and synthesis:** Integrating findings into successive, higher levels of aggregation and analysis; Identifying continuities and discontinuities between the NRDS and TYIP (horizontal) and the subsidiary strategies and interventions (vertical); and Identifying and summarising main findings and lessons learnt.

The starting point for our study was to develop a common understanding among the review team members of the two key documents (NRDS and TYIP) and how to undertake the individual review reports. Over the course of the study, four team meetings were held (April, June and September 2019 and January 2020). The team tried to ensure throughout the review process to be self-critical and reflexive about our final assessments, conclusions and recommendations. The team consisted of a number of (senior) members who can be considered to have been 'insiders' to the policy and strategy decisions and developments of the past two decades. This could be seen as a potential source of bias by an external observer with the critique that these individuals were too 'close' or 'involved' in the development, implementation and or reviews of the

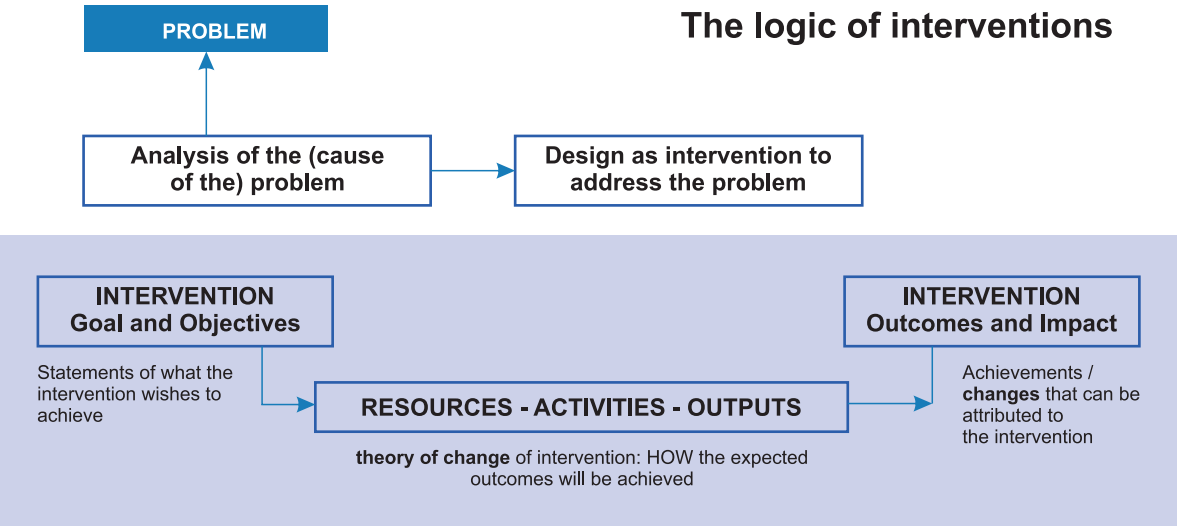
NRDS/TYIP and their subsidiary strategies. However, our approach has been to make explicit the possible ways in which individual opinions could have shaped such developments and to reflect on the consequences thereof at every one of our team meetings. Individual opinions and interpretations were voiced but also critiqued and tested against the consensus view of the team as well as more 'objective' sources of evidence.

2.2 The study design

Reviews are part of the family of evaluation studies – whether these are referred to as evaluations, assessments, reviews or sometimes even audits. The field of evaluation studies has its academic origins in the work of such pioneers as Donald Campbell, Thomas Cook, Michael Scriven, Michael Patton, Carol Weiss and many others in the 1960s and today. Scriven is famous for introducing the distinction between 'formative' and 'summative' evaluations in 1980. Patton and Weiss alerted us to the problems of evaluation 'use'. The initial emphasis on so-called 'black box-evaluations' by Campbell and Stanley was quickly and decisively replaced in the 1980s and 1990s by realist and theory-based evaluations (Chen, Lipsey, Pawson and Tilley and others). These authors emphasised that good evaluation practice requires an understanding of the (implicit or explicit) theory of change of interventions. The paradigm of realist evaluation practice has been challenged by various other approaches, but remains the gold standard in evaluation practices worldwide.

Interventions, as understood in the field of monitoring and evaluation studies, have a standard logic: they have goals and objectives (which address some problem or gap or challenge), and these goals and objectives point to some future anticipated outcomes and eventual impact (see Figure 1 below). In order to optimise the achievement of these outcomes, we must engage in appropriate activities and produce outputs that will most likely produce the anticipated outcomes. It is this combination of activities and outputs that will most likely produce the desired outcomes and impact that constitute the intervention's theory of change. Theories of change are often formulated as a chain of causes and effects (although not in a simple linear fashion).

Figure 1: The logic of interventions



Ideally, interventions follow a life cycle from conceptualisation and design through to implementation and expected outcomes and impact:

- *Conceptualisation* refers to the initial phase where goals and objectives are formulated to address a problem that has been identified.
- *Design* refers to the second phase where an assessment is made about the resources that are required to implement the intervention to achieve optimal impact. Design issues typically address what is required in terms of human resources, funding, infrastructure, delivery systems and time.
- *Implementation* refers to the actual delivery of the intervention. Implementation can be undertaken centrally and located with a single agent, or in a decentralised and distributed manner across multiple sites.

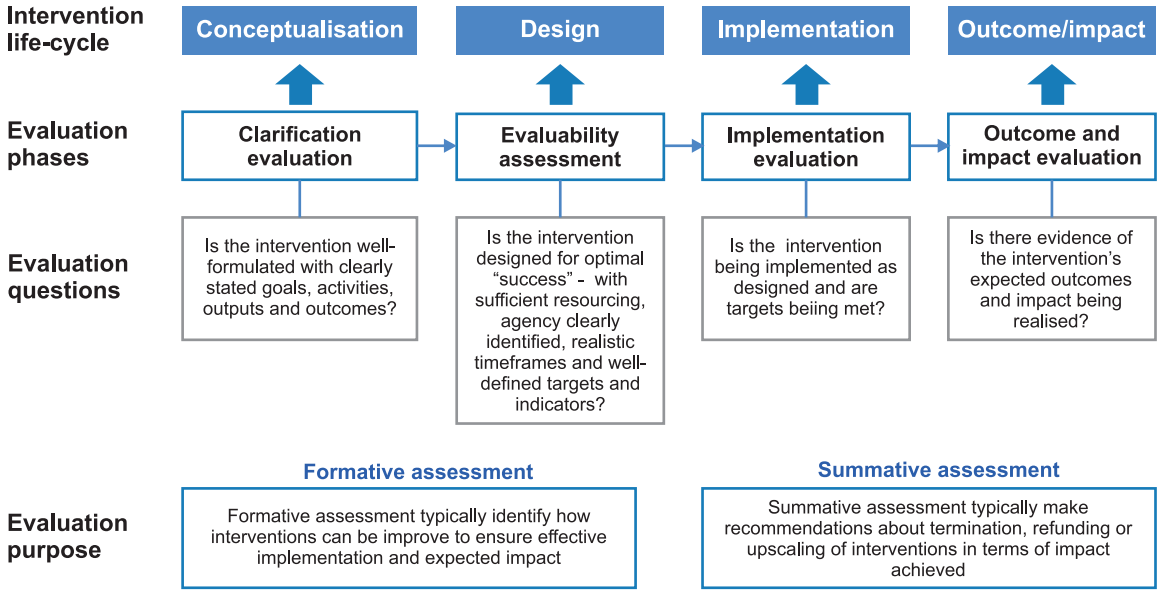
- *Outcomes and impact* refer to the expected (positive) change(s) that will occur if the intervention is successfully implemented. Intervention impact is positive when the problem that has been targeted is successfully resolved.

When we evaluate or assess an intervention, our evaluation questions mirror the stages in the intervention life cycle. This is illustrated in Figure 2 below, which introduces the following key concepts:

- *Clarificatory evaluation* questions are aimed at the conceptualisation phase;
- *Evaluability assessment* addresses issues related to design;
- *Implementation evaluation* asks whether the intervention is implemented properly and as designed; and
- *Outcome and impact evaluation* questions ask whether the intervention has produced the desired outcomes, effects and impact.

Figure 2 also introduces the notion of the evaluation purpose and distinguishes between formative and *summative* purposes in evaluation. This is a classic distinction introduced by Michael Scriven in 1980:[8] "Evaluations may be done to provide feedback to people who are trying to improve something (formative evaluation), or to provide information for decision-makers who are wondering whether to fund, terminate or purchase something (summative evaluation)." In our review of the NRDS and TYIP, we pursued both evaluation purposes: The ToR explicitly indicated that we should make 'pronouncements' about possible improvements to policy and strategy design (formative assessment), and draw conclusions on what has and has not been achieved (summative assessment).

Figure 2: Linking evaluation purpose and questions to the intervention life-cycle

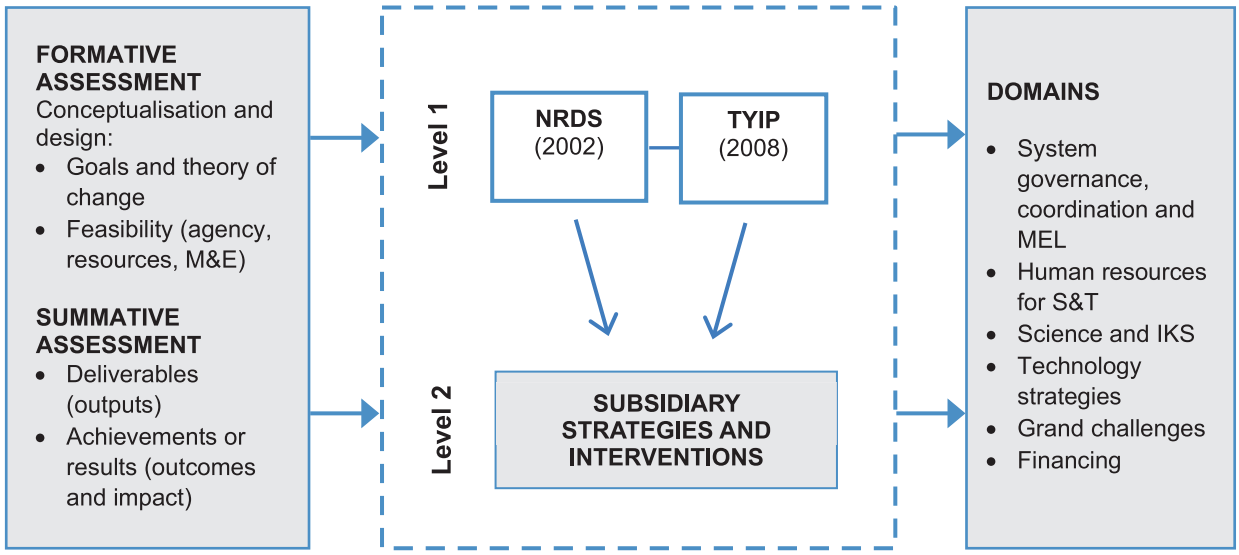


2.3 Analytical framework for the review

Figure 3 below presents a summary view of the main features of our analytical framework. The diagram shows (in the central block) that our analytical focus is both on the NRDS and TYIP as strategic frameworks (Level 1 analysis) as well as the 21 subsidiary strategies and interventions that are referenced in these two documents (Level 2 analysis). The block on the left indicates that at both levels of analysis we undertook formative and summative assessments. The block on the right indicates the five domains into which we organised the substantive foci of the two documents, along the lines of which we ultimately organised and presented the results of our analyses.

8 Scriven M. 1980. *The Logic of Evaluation*. Edgepress. pg6-7.

Figure 3: Analytical framework for the review



The diagram shows that there is a clear symmetry in our analysis across these two levels of analysis: both entailed formative and summative purposes. However, there are also clear differences in how these two forms of assessment were ultimately undertaken at each level. These differences are the result of the different sources and availability of evidence utilised in drawing our conclusions at each level. These differences are elaborated on in Tables 1 and 2 below.

Table 1: Review methodology of the NRDS/TYIP (Level 1 analysis)

Formative assessment	Summative assessment	
	Indicator-based assessment	Secondary data: evidence sourced from the NACI indicator reports as well as international innovation scoreboards.
Review of the NRDS/TYIP in terms of standard clarificatory evaluation and evaluability assessment questions about clarity of goals, objectives, theory of change, clarity of outcome statements, targets and indicators.	Assessment of expected outcomes and impact of the NRDS/TYIP as reflected in the targets and indicators included in the documents.	Overall assessment of the NRDS and TYIP benefits from references to the conclusions and results of previous system-wide reviews (2007 OECD Review, Ministerial Reviews 2012 and 2017).

Table 2: Review methodology of the individual strategies/interventions (Level 2 analysis)

Formative assessment	Summative assessment		
	Indicator-based assessment	Secondary data: evidence sourced from previous reviews	Primary data and evidence sourced for this review
Review of subsidiary strategies/interventions in terms of standard clarificatory evaluation and evaluability assessment questions about clarity of goals, objectives, theory of change, clarity of outcome statements, targets and indicators. Here the formative assessment also established whether there was a clear implementation plan with targets and indicators.	Summative assessments could be undertaken in those cases where indicator-based data on the outcomes and impact of the strategy/ intervention were available. However, where the formative assessment showed that a particular strategy/ intervention was not well formulated and there was no implementation plan, we were not able to draw any summative conclusions.	Where available, evidence from previous studies or reviews relating to specific strategies or interventions was utilised in the summative assessments in terms of both implementation and outcomes and impacts.	Where possible, the draft reviews were sent to the relevant directors at the DSI (e.g. those in charge of the grand challenges), to elicit their comments on whether our assessments (formative and summative) were accurate and fair, and/or to experts in the relevant field for additional information and clarity.

2.4 A note on the complexities of policy-making and implementation

The analytical framework for this review is rooted in the practice of evaluation logic frameworks and designs. As such, it mirrors what is generally referred to as the 'policy stages' conception of policy-making and implementation. In this, the policy process involves the stages of agenda-setting, problem definition, policy formulation, decision-making, policy adoption, implementation, evaluation, termination or continuation, as well as a feedback loop to problem identification based on the outcomes of the evaluation phase. There is also an assumed rationality underpinning this depiction of the policy process.

However, as scholars in the fields of policy analysis and public administration have shown, in reality, policy-making and implementation seldom happen in this way. For instance, in some cases, stages of the process interact out of step (e.g. implementation can affect agenda-setting and evaluation can be applied to all stages), occur in reverse order or are omitted altogether. Furthermore, the policy process is not a simple linear, rational exercise. It is influenced by political, fiscal and other considerations; involves multiple actors and networks both within and outside of government; and is characterised by bargaining, negotiation and compromise among (often competing) interests. Sometimes particular policy problems are identified or prioritised not on the basis of a rational assessment of the policy context, but because of the interests or agendas of particular government officials or politicians, while certain decisions are made for the sake of expediency or to satisfy the demands of a particular constituency. Sometimes policy imperatives shift away from the original focus as codified in, for example, a national strategy or plan, because of changes in the external environment which require a different type of policy response.

The relevance of this for this review of the NRDS and TYIP is that the analysis and conclusions drawn are based, to a large extent, on a review of formal documents (the NRDS, TYIP and subsidiary strategies and implementation plans). More nuanced insights about some of the dynamics behind official accounts and what can be gleaned from documents, from external commentators and those team members who have more of an 'insider' perspective, are highlighted in the Main Report and the reviews of subsidiary strategies and interventions. However, these are relatively and necessarily limited, as such inside information was for the most part not visible to the review team. It is thus recommended that readers of this report take this into account and draw on their own knowledge and experience of policy developments in a further interpretation of the findings of this review.

CHAPTER

3

METHODOLOGY

The main focus of this chapter is the methodologies and processes we employed in undertaking the Level 1 and Level 2 analyses.

We also address other methodological matters, including (a) issues related to access to documents and previous reviews, (b) the different sources of evidence drawn upon (triangulation), and (c) matters related to ethics and confidentiality. We conclude the chapter with a discussion of how we have approached the analysis of the continuities and discontinuities between the NRDS and TYIP (horizontal), and these two strategic frameworks and the subsidiary strategies and interventions included in the review (vertical).

3.1 Access to documents and previous reviews

As part of the project management, a repository of documents was created on MS Teams where individual team members could upload their own documents or download common documents as and when required. We went to great lengths to gather as comprehensive a list as possible of all documents that could be relevant to our review. We grouped these documents into four categories:

- Core documents (Level 1): these include the 1996 White Paper, NRDS, TYIP and the 2019 White Paper.
- Subsidiary strategy/intervention documents (Level 2): these include the source documents related to each of the 21 strategies and interventions that we reviewed, and typically included the original formulation of the strategy or intervention as well as derivative documents, such as implementation frameworks and plans.
- Past reviews: these include both system-wide reviews (such as the OECD Review of 2007[9] and the Ministerial Reviews of 2012 and 2017), as well as strategy-specific evaluations and reviews (e.g. the reviews of the Centres of Excellence programme in 2007 and 2012).
- Technical (consultancy) reports and academic studies (journal articles) relevant to the review: these included the annual R&D Survey reports, various studies by CREST and other agencies, the NACI STI Indicator reports, among others.

Although we eventually gained access to many of the documents that we required and requested, we could not in the final analysis gain

9 OECD. 2007. *OECD Reviews of Innovation Policy: South Africa*. Paris: Organisation for Economic Cooperation and Development.

access to all documents. For example, we requested access to reviews that we know have been conducted (such as the review of the Advanced Manufacturing Technology Strategy commissioned by the Department of Planning, Monitoring and Evaluation, and a recent review of National Intellectual Property Management Office) but were not granted access to these. In some cases, we were informed that our requests referred to internal departmental documents that were confidential.

We also requested information about expenditure on specific programmes from the DSI. We acknowledge the willingness of the respective officials who assisted with these requests. The resultant information was utilised both in the individual reviews as well as in our discussion of the main findings.

3.2 Process of undertaking the individual reviews

The formative and summative assessment of the NRDS and TYIP documents were primarily undertaken by staff at SciSTIP with specific inputs (especially initially) by other team members. At our final team meeting in January 2020, the results of these two assessments (Volume 2, Chapters 1-4) were submitted to the whole team for input and comment.

The authors of the individual reviews (see Preface to this report for the list of reviewers) compiled draft review reports, drawing on all relevant sources of evidence (see section 3.4 below). The draft reviews were then sent to either another member of the team for further comments and critique and/or an expert in the field or appropriate official at the DSI for comments. At the final team meeting in January 2020, each review was discussed by the entire team and further suggestions were made for improvement towards finalisation.

3.3 Review methodology for the Level 1 analysis of the NRDS and TYIP

3.3.1 Formative assessment of the NRDS and TYIP

The formative assessment of the NRDS and TYIP documents comprised a clarificatory evaluation and evaluability assessment.

Clarificatory evaluation speaks to issues related to the *logic and structure* of a strategic framework and specifically asks whether the framework is (a) appropriate to the problems and challenges it wishes to address (relevance), and (b) properly conceptualised. Clarificatory evaluation therefore typically includes the following questions:

1. Has the strategy been designed on the basis of a proper problem or needs analysis?
2. Are the goals and objectives of the strategy clear and unambiguously formulated, and is there an explicit theory of change which stipulates how (through which interventions, programmes, initiatives) the expected outcomes and impact of the strategy will be achieved?
3. Does the strategy take into consideration the specific contextual factors that may impact (positively and/or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the strategy were aware of potential risk factors that may impact negatively on the achievement of strategies objectives?

Evaluability assessment speaks to issues about the *feasibility of the design* and the risks that may mitigate against its likely success. These issues lead to questions such as the following:

4. Is the strategy sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it? In other words, is it clear who will take responsibility for specific strategies and be accountable for the implementation of such strategies?
5. Is the strategy sufficiently clear about the resources (especially funding and infrastructure) that will be required to implement its various interventions to optimise success?
6. Does the strategy specify how its progress and ultimate achievements and impact will be monitored and evaluated? This speaks to issues around indicators, targets and evidence of achievement.

These six questions were used as the review template for the formative assessment of the NRDS and TYIP. The following rating legend was employed:

- To a large extent addressed
- Moderately well addressed
- Addressed only in parts
- Poorly addressed or not addressed at all

3.3.2 Summative assessment of the NRDS and TYIP

The summative assessment of the NRDS and TYIP was undertaken on the basis of performance indicators.

The NRDS and TYIP include tables with high-level indicators (and targets). These indicators are 'loosely' linked to the (implicit) theories of change embedded in each document. However, we need to distinguish between two different 'types or levels of indicators': (1) indicators explicitly referenced in the NRDS and TYIP, and (2) indicators only found in the subsidiary strategy documents (and, where available, associated implementation plans). The indicators that are specific to the individual strategies are discussed in the individual review reports in Volume 5 of our report.

As far as the first category of indicators is concerned, we combined the indicators from the NRDS and TYIP into one document (many of the indicators straddle these two documents) and subsequently populated all these indicators with the most recently available data (up to 2018). This allowed us to make an assessment of whether the targets that had been set in the NRDS and TYIP with regard to R&D expenditure, human resources for S&T, achievement of world class science, technology outputs and patents, and so on, have been met. We present the results of this assessment in Volume 2 (Chapter 4: Indicator-based assessment).

3.4 Review methodology for the subsidiary strategies and interventions (Level 2 analysis)

3.4.1 Process of selecting the subsidiary strategies and interventions for inclusion in the review

Our point of departure in identifying the subsidiary strategies and interventions to include in our review was to work through the NRDS and TYIP and extract the substantive foci in each of these documents. These are listed in Table 3 below.

Table 3: Substantive focus areas identified in the NRDS and TYIP

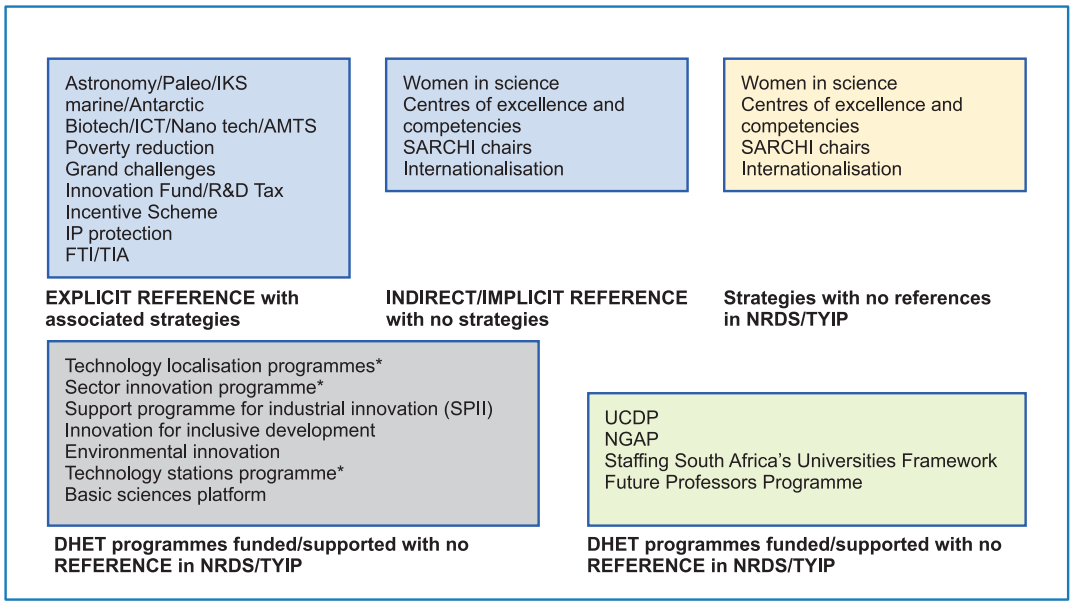
Domain	Description	Substantive focus areas in the NRDS and TYIP
System-level governance, coordination, financing, and monitoring, evaluation and learning (MEL)	Generic initiatives aimed at improving system-level governance and coordination of research and S&T, chiefly as facilitated through the DST; without any specific focus on medium-term innovation and economic impact	Regulatory framework Policy development, strategies and plans Intellectual property National R&D budget Public expenditure R&D tax incentive Funding and especially coordination of different funding instruments (TIA, Innovation Fund) Review and alignment of government funding National risk management and foresight RDI across government/coordination Monitoring and evaluation
Human resources for S&T	Generic and policy activities related to the development and strengthening of human resources for S&T, including international S&T cooperation	Overarching strategy/plan for STI Initiatives (CoEs, SARChI) Transformation (gender, race) HCD embedded in other policies/strategies International cooperation/partnerships Science education/public understanding of science

Domain	Description	Substantive focus areas in the NRDS and TYIP
Science and indigenous knowledge systems	Imperatives focused primarily on knowledge generation and associated HCD as part of the national science enterprise, generally with no specific medium-term focus on innovation and economic impact	IKS Palaeontology Antarctic and marine science Astronomy Biodiversity Geo-systems and environmental sciences Biosciences
Technology strategies	Imperatives aimed at developing technological R&D in specific areas, different from basic research, and with a medium-term focus on innovation and economic impact	S&T for poverty reduction/vaccine development ICT Advanced manufacturing/smart materials/ encryption/fluorine/chemicals Deep mining Microsatellite engineering Biotechnology Nanotechnology
Grand challenges	Integrated initiatives to address high priority societal problems through science, human resources development and technology development	Farmer to Pharma/bio-economy Global change/climate change Space S&T Energy security Human and social dynamics

In working through the NRDS and TYIP we soon realised that neither document followed standardised terminology when referring to specific actions or interventions that should be implemented. Not only are such actions or interventions variously referred to as strategies, programmes, initiatives, grand challenges or actions but the references to these range from very explicit interventions (such as the Biotechnology Strategy) to passing and even implicit references (such as the indirect reference to the SARChI programme through the inclusion of a target in an indicator table in the TYIP). We distinguish between these two types of referencing in the blue blocks in Figure 4 below.

In addition, the project team was aware of many other initiatives that had been managed by the DST, dti, TIA and DHET in the period between the publication of the NRDS in 2002 and the start of this review in 2018. These initiatives have received funding and, in some cases, can be linked (mostly indirectly) to the NRDS and TYIP (see programmes in the grey blocks). Finally, the diagram indicates some other strategies that were developed and implemented during this period, and which address key imperatives of the NRDS and TYIP (green block).

Figure 4: Mapping the subsidiary strategies and interventions linked to the NRDS and TYIP



Based on this analysis, we ultimately only selected specific interventions and strategies for more in-depth review where these were either explicitly or implicitly referenced in the NRDS and TYIP (the blue blocks). Where appropriate we do, however, make reference to the other interventions identified above. It is clear from this 'classification' of subsidiary strategies, interventions and instruments, that the team had to delimit the scope of the review very clearly. The scope of the ToR can be understood to range from the very broad perspective of implying a review of the entire STI to a very narrow perspective of only focussing on the two strategy-wide frameworks (NRDS and TYIP). Our approach can be located somewhere in the middle between these two extremes. We did focus on the two key documents (NRDS and TYIP) and undertook both a formative and summative assessment of these. We also subsequently, as highlighted above, identified those subsidiary strategies that are more or less explicitly referenced in the NRDS and TYIP and conducted reviews of these. However, it is important to emphasise that our reviews of these individual strategies and interventions were confined to existing information (previous reviews and evaluation studies, other studies, reports and feedback from implementing agencies as well as engagement with selected key informants). Our reviews should not be seen as independent and external evaluations in the strong sense of the word. It would also be impossible to conduct such external evaluations of each of the 21 strategies identified within the budget and timeframe of the study.

Our reviews of the subsidiary strategies and interventions combined formative and summative assessments across the spectrum of evaluation phases – from clarificatory evaluation to outcome evaluation (where possible). In the next two sections we describe the approaches used to undertake the assessments.

3.4.2 Template for the formative assessment of the individual reviews

The formative assessments of the subsidiary strategies and interventions involved asking questions such as the following:

- Is any background or relevant context provided about the rationale and timing of the strategy or intervention?
- Are the goal(s) and subsidiary goals or objective statements clear and well-formulated?
- Are the proposed actions and activities that will be implemented to achieve the stated goals clearly and concretely specified? (These activities together constitute the presumed mechanisms of change; i.e. the theory of change of the intervention.)
- Is agency specified? In other words, who will implement these actions?
- Are the outputs (the results of the activities, or deliverables) clearly specified? Are timeframes and (usually quantifiable) targets specified?
- Are the anticipated short- and medium-term outcomes specified?
- Are any indicators (mostly of outcomes and impact) specified as well as what the sources of evidence of such indicators would be?

It should be noted that the extent to which the questions above could be answered depended on the level of detail in the strategy or intervention documents. If the document had been well-structured and followed the main logic and structure of interventions, it would be possible to answer many of these questions. However, if the document was vague, lacked detail and contained little or no information on implementation or milestones, then the reviewers were constrained in the kinds of judgments that could be made, especially about outputs, outcomes and possible impact.

In order to ensure consistency and comparability across the final individual review reports, the team used a review template developed for this study (see Table 4 below) that is based on standard clarificatory or design evaluation approaches.

Table 4: Template for the individual reviews

Context	• Is any reference made to problems or challenges being addressed by the strategy? • Is any reference made to specific policy (e.g. White Paper) or strategy (e.g. NRDS) documents? • Is any reference made to other relevant factors that explain the rationale behind the strategy?
Goal statements • Goal statements are statements of desired end-states – what we would like to achieve. When we formulate a goal (statement) we are specifying what we want to achieve (what we want to have changed). Goal statements point to the future: hence they typically refer to expected outcomes in the future.	• Are the goal statements well formulated; i.e. clear and unambiguous?
Subsidiary goals or objectives • It is typical to find that an intervention/programme may have one overarching goal statement, but multiple sub-goals (sometimes referred to as 'objective statements').	• Are the sub-goals well formulated and clear? • Do the sub-goals or objectives together sum to the expected outcomes of the primary goal statement?
Intervention activities and agency • The set of activities that will be implemented form the heart of the intervention. They tell us what the 'designer' of the intervention thought needs to be done to ultimately achieve the desired outcomes. These activities together constitute the presumed theory of change of the intervention. In addition, it is required that agency is specified (i.e. who will implement these actions).	• Are the activities sufficiently specific, concrete and measurable? And is it clearly specified who will undertake these activities? • Are there sufficient resources (financing, human resources, time) for conducting these activities? • What are the conditionalities inherent in these activities? Stated differently: do some activities depend on others for their successful implementation? • Are all the required activities listed that should produce the desired outcomes, or are some critical activities (obviously) not listed?
Outputs and targets • 'Outputs' or 'deliverables' are what results from our activities. It is often the case that targets (quantities of outputs) and milestones (outputs against timeframes) are set for the production of such outputs.	• Are intervention outputs clearly specified? • Are targets specified and are these realistic and achievable? • Are milestones specified and are these realistic and achievable?
Outcomes, outcome indicators and sources of evidence • Outcomes are the effects or results of our interventions. They can be short-, medium- or long-term. Intervention impact is often defined as the aggregate or combined sum of such outcomes. Indicators are indirect measures of objects/phenomena that we cannot measure directly. They are employed when we cannot directly measure or assess the achievement of outcomes that are typically abstract. In research methodology they are typically the result of operational definitions of constructs.	• Are intervention outcomes clearly specified? • Is a distinction made between short-term and medium-term outcomes? • Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable? • Is reference made to any primary or secondary sources of evidence of such indicators?

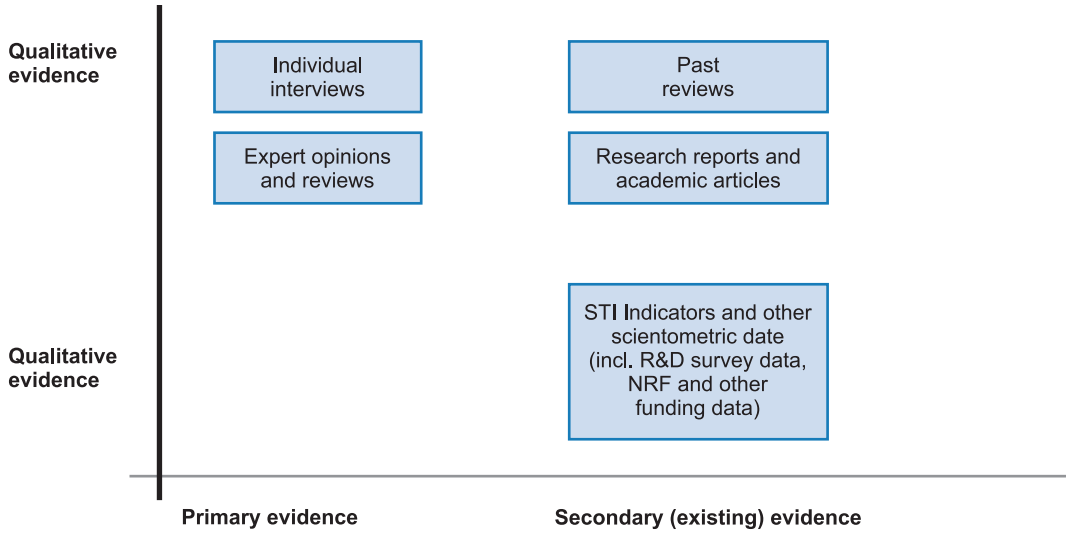
As the reviewers worked through the individual strategies/interventions it soon became clear that we faced a number of challenges:

1. Some of the individual strategies and interventions did not meet the minimum criteria of good conceptualisation and design. In some cases, the documents did not contain well-formulated goal and objectives statements. Similarly, even where these were in place, it was not necessarily the case that the other required components of a well-formulated strategy or intervention were present (e.g. specification of intervention activities, outputs and outcomes).
2. A number of the strategies did not have associated implementation frameworks or plans. In these cases, the reviewers were hamstrung in assessing how the strategy was implemented, if at all. Of course, we also found cases of very detailed implementation plans with clearly defined activities, outputs, targets and even (performance and outcome) indicators.
3. The presence of an implementation plan did not mean that the listed activities were in fact implemented and outputs and outcomes achieved. In order to make a judgment on the actual implementation and outcome/impact of a strategy, further evidence needed to be gathered and analysed.

3.4.3 Methodology and evidence used for the summative assessment in the individual reviews

Any evaluation study faces the same challenges about the quality and credibility of different sources of evidence. It is customary to distinguish between primary and secondary, and qualitative and quantitative, forms of evidence. Using these distinctions, we summarise the main categories of evidence that we utilised in Figure 5 below.

Figure 5: Triangulation: Types and sources of evidence



Individual reviewers utilised a number of sources of evidence during this process, including:

- Evidence of implementation as contained in implementation and performance reports from the agency/department implementing the strategy or intervention.
- Evidence as contained in previous studies (including evaluation studies and academic papers) that assessed the intervention.
- Evidence about implementation gathered through primary data collection (personal interviews or email requests).
- Evidence about funding for the strategy (mostly from the DSI directly but also from other departments and agencies).
- Indicator-based evidence: where relevant, a strategy may have included reference to different kinds of indicators (scientometric, bibliometric, economic, etc.). In such cases, we updated the data for these indicators to the most recent available year.

Once the phase of gathering evidence was completed, the reviewers concluded their review reports with a summative assessment of the key objectives and outcomes of the intervention. This summative scorecard took the form of a (colour-coded) judgment as per the following four categories:

- Achieved
- Not achieved at all
- Partially achieved
- Not possible to make a judgement

3.4.4 Ethics and confidentiality

As indicated above, this study mainly utilised existing quantitative and qualitative data sources. All the documents listed as references are publicly available or have been made available to the team by the DSI for inclusion in the study. A small number of personal interviews were conducted with key informants. In addition, individual feedback was also solicited by email and phone from key experts. The team applied to Stellenbosch University for ethical clearance for the study. Such approval was given in July 2019 before any of the individual interviews commenced. At the request of some of the key informants, we do not name them in our list of acknowledgements.

3.5 Outline of report

The final phase in our study consisted of integrating the findings of our assessments of the NRDS and TYIP (as standalone documents) with the findings of the 21 subsidiary strategies and interventions included in the review. The process of integrating our findings involved aggregating the results of our reviews across the two levels of analysis as well as over time. The main findings of the study are presented in Volumes 2 and 3 of this report. Our high-level learnings, reflections and recommendations are found in Volume 4 of the report.

Volume 2

FORMATIVE AND INDICATOR-BASED ASSESSMENT OF THE NRDS AND TYIP

CHAPTER 1

INTRODUCTION AND CONTEXT OF THE NRDS AND TYIP

1.1 Introduction

At the time of undertaking this review, the NRDS and TYIP were 18- and 12-years-old, respectively. Over this period, the NSI has evolved, and the macro-level socio-political and socio-economic environment in which the NSI is embedded has changed too. In addition, the political narrative has changed significantly during this time, possibly more than the objective, material context for STI in South Africa. It is important in reviewing progress against the strategies to do so in their own context, and not let contemporary contexts influence that review, no matter how important the new context and its demands may be: any strategy is drafted in light of the existing imperatives at the time of its conceptualisation, as well as the foreseeable changes in that context. Where the changes that actually emerge are different from those foreseen when drafting the strategy, this does not undermine the value of the strategy in its own context.

As is typically the case with many high-level strategies and policies, the narratives of the NRDS and TYIP make reference to a wide range of priorities, imperatives, recommendations and observations, although not all of them are likely to be equally important from a strategic point of view. Also, both documents occasionally list *examples* of possible initiatives or areas of focus by way of illustration, rather than as explicit strategic imperatives, although the distinction between them is not always clear. In preparing to review national progress against these two strategic frameworks, it is therefore necessary to summarise their key intentions as they are set out in qualitative and/or quantitative terms, lifting out essential elements above the less essential ones. Inevitably, this process has required some choices to be made, but that does not imply an arbitrary approach. By way of example, the context for a specific recommendation is usually a useful indicator, as is the extent of repetition and depth of reflection. We could thus conclude that not every good idea mentioned in either of these documents was intended to assume the status of a national strategy or imperative.

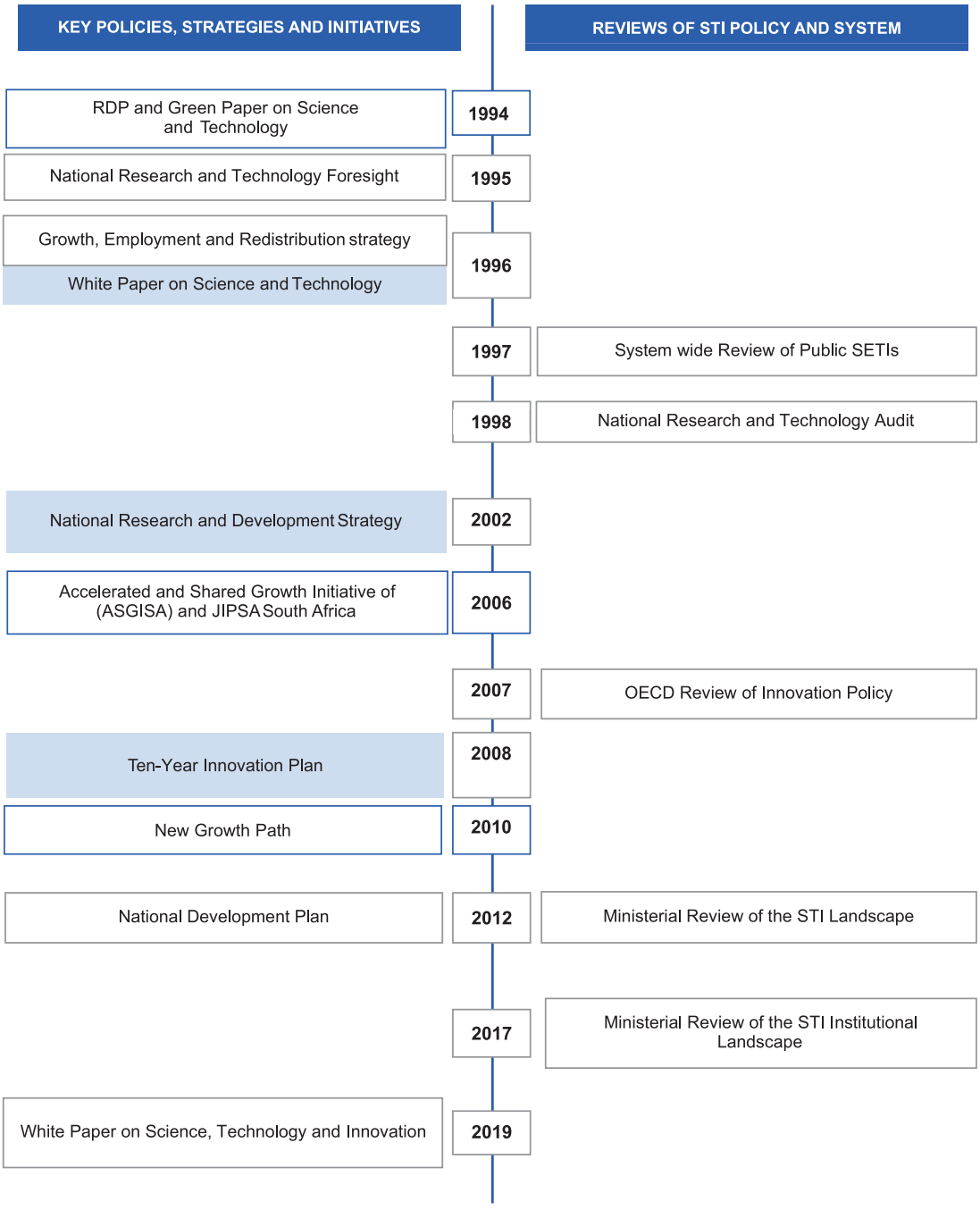
The distinction between the National Research and Development *Strategy* and the Ten-Year Innovation *Plan* does not coincide fully with the standard distinction between a 'strategy' and a 'plan'. The TYIP is clearly not simply the 'implementation plan' of the NRDS. The TYIP does have features (indicators, targets) that one would typically find in an implementation plan, but it also shows more similarities to a high-level strategy or even a vision document.

Unsurprisingly, neither the NRDS nor the TYIP are consistent in the use of key monitoring and evaluation (M&E) terminology such as indicators, outcomes or targets (e.g. the TYIP often confuses indicators with either

outcomes or targets). As pointed out above, neither of the two documents (especially the NRDS) are explicit about when something is a strategy or something else (e.g. a broad initiative or a programme). Furthermore, both documents are weak in terms of explicating the underlying theories of change of the proposed strategies. In cases where they do so, the proposed theory of change is not underpinned by sufficient or extensive supporting evidence. In addition, there is a lot of slippage around terminology: in addition to the term 'strategy', other terms – such as missions, challenges, programmes – are also used to refer to what needs to be addressed. And, as we will see, both documents make reference to specific 'strategies' (e.g. a bio-economy strategy or the space science strategy) for which subsequent implementation plans were developed.

A timeline showing the main policy and strategy documents, as well as key system-wide and broad review processes, spanning this period is provided in Figure 1 below.

Figure 1: Key STI-related policies, strategies, plans and reviews



By way of contextualising the NRDS and TYIP, we provide a brief overview of the core policy issues and initiatives highlighted in the 1996 White Paper on S&T.

1.2 The 1996 White Paper on S&T

Vision of the White Paper

In the introductory chapter (DACST, 1996: 3), the White Paper sets out its overarching vision and goals for innovation policy in South Africa, as highlighted in Box 1 below.

Box 1: The 1996 White Paper's vision and goals for an innovation policy for South Africa

The White Paper is based on a view of the future where all South Africans will –

- enjoy an improved and sustainable quality of life;
- participate in a competitive economy by means of satisfying employment; and
- share in a democratic culture.

In order to attain this vision, the following three goals pertinent to the creative use and efficient management of innovation will have to be achieved:

- The establishment of an efficient, well-coordinated and integrated system of technological and social innovation within which –
  - — stakeholders can forge collaborative partnerships and interact creatively in order to benefit themselves and the nation at large;
  - — resources from engineering, the natural sciences, the health sciences, the environmental sciences and the human and social sciences are utilised for problem-solving in a multidisciplinary manner;
  - — stakeholders, especially those who were formerly marginalised, are part of a more inclusive and consultative approach to policy decision-making and resource allocation for science and technology (S&T) activities.
- The development of a culture within which the advancement of knowledge is valued as an important component of national development.
- Improved support for all kinds of innovation which is fundamental to sustainable economic growth, employment creation, equity through redress and social development.

The White Paper took as its point of departure the adoption of the notion of a 'national system of innovation' as a framework for guiding the development of S&T policy that would contribute to harnessing STI towards addressing national socio-economic needs. It defined an NSI as "a set of functioning institutions, organisations and policies which interact constructively in the pursuit of a common set of social and economic goals and objectives" (p11). The White Paper recognised the linkages between S&T policy and policies and strategies in other domains, including those relating to macro-economic policy and education and training, and highlighted the coordinating role of the Department of Arts, Culture, Science and Technology in the implementation of interventions (p6).

Fundamental requirements for an S&T policy

With regard to meeting the dual demands of "maintaining cutting edge global competitiveness" and "addressing the urgent needs of those of our citizens who are less able to assert themselves in the market", the White Paper set out the following fundamental requirements for a "sound S&T policy" (p7):

- Promoting competitiveness and employment creation
- Enhancing the quality of life
- Developing human resources
- Working towards environmental sustainability
- Promoting an information society

- The importance of knowledge generation
- The role of the human sciences in innovation, and
- Finance, management and performance.

With regard to promoting competitiveness and employment creation, the White Paper noted (p7):

- "Recognising that business is the driving force behind the economy, Government must provide the leadership, incentives and support that the business sector needs to meet the new challenges posed by highly competitive markets."
- "South Africa's support structure for creating and sustaining micro-enterprises and small businesses will require a strong technology component."
- "Public investment in R&D needs to be redistributed away from the support of activities within the Government's own facilities and towards more comprehensive support of R&D performed in the private sector."
- In order to "enhance the rate and quality of technology transfer and diffusion" from the SET sector, "quality human resources, effective hard technology transfer mechanisms and the creation of more effective and efficient users of technology in the business and government sectors" would be required.
- Entrepreneurship needs to be fostered, "particularly among those historically excluded from the formal economic sector", and must be "linked to the promotion of innovation".

In terms of **enhancing quality of life,** the White Paper emphasised those "domains where market failure is high", including environmental sustainability; health care provision; meeting the needs at the community level; reducing the total cost of infrastructure provision; and providing safety and security for all (p8). Reference is also made to ensuring that an "appropriate" proportion of science spend is allocated to these areas, and that "communities need to be encouraged to adopt social and technological innovations to assist them in decision-making and to enhance their ability to make informed decisions" (ibid.).

The **development of human resources** was set against the backdrop of "innovation-assisted economic growth" and the "equalisation of income and economic opportunities" (ibid.). Specific reference was made to the need for lifelong "scientific and technical education, training and learning among the work-force and among South Africans in general", as well as new approaches to education and training (curricula and training programmes) "that will equip researchers to work more effectively in an innovative society" (ibid.).

Working towards environmental sustainability focused on reconciling economic growth with "considerations of environmental impact, resource constraints and conservation", and the need for regulatory mechanisms that will reduce the negative impacts of "technology introduction, transfer and diffusion" (ibid.). Alongside this was the need for "[e]nvironmental research, monitoring and control", the "development and improved availability of environmental technologies", environmental management, and a national strategy for the implementation of the Agenda 21 terms of agreement on environmental sustainability (ibid.).

The **promotion of an information society** sought to take advantage of the information revolution for all South Africans across the board. Specific mention was made of using information technology (IT) "to serve people issues such as supporting education, providing household services and enabling social development" (p9).

The **importance of knowledge generation** was linked to the international trend towards harnessing research to contribute to economic growth. However, the White Paper was cautious about taking "too economistic a viewpoint", emphasising the importance of curiosity-driven or basic research, particularly in universities and the erstwhile Technicon's, the link between scientific endeavour and "cultural and social values", and the importance of maintaining "a basic competence in 'flagship' sciences such as physics and astronomy for cultural reasons" (ibid.).

The **role of the human sciences in innovation** was also highlighted, particularly with regard to providing "an understanding of social processes and problems and to act as a source of social innovation"; facilitating "appropriate technological change" in society and economy; providing "the basis for policy analysis"; and providing a "source of new knowledge and informed critique of the transformation of South African society and its economy" (ibid.).

Finally, the focus on **finance, management and performance** recognised the "limitations imposed on research, technology development and technology transfer" by fiscal constraints (ibid.). The need for "linkages between universities, [SETIs] and the private sector … with a view to sharing risks, resources and insights with respect to pre-competitive research" was highlighted (ibid.). Specifically in terms of performance, the White Paper referred to "managing the problems of big science, fundamental research and service-oriented science and their relationship with technology development, infrastructure, basic needs provision and human resource development", as well as the need for "the comprehensive measurement of the inputs and outputs of S&T research and development, and their impact on the goals of national policy objectives, both in S&T and other fields" (ibid.).

Six initiatives underpinning the White Paper's S&T policy

The core of the White Paper sets out six broad initiatives which it divided into those that fall under the domain of government functions (policy formulation and resource allocation at the national level, and regulatory policy-making), and shared functions – that is, those which "are dependent upon the activities of many stakeholders" (p10). The latter include: performance-level financing of innovation-related activities; performance of innovation-related activities; human resource development and capacity building; and the provision of infrastructure. These are unpacked in brief below.

Policy formulation and resource allocation

In response to the inheritance of a fragmented and poorly-coordinated S&T system, the White Paper proposed the establishment of new institutional mechanisms and associated responsibilities at national level. In addition to the already-established Ministry and Department of Arts, Culture, Science and Technology, and the Ministers Committee for Science and Technology (MCST), the White Paper indicated that the Minister would be responsible for the establishment of the National Advisory Council on Innovation (NACI), the National Research Foundation (NRF) (support to research and research capacity building), the Innovation Fund, and the National Facilities for Research (p19).

Multiple functions were assigned to DACST in terms of its overarching coordination role in the system. These related to, among others (ibid.): promoting coherence and consistency in government's approach; promoting and coordinating "interdepartmental and government-wide initiatives relating to the support of innovation and technology diffusion"; directing the preparation of the Science Budget; and designing a comprehensive framework addressing the management and oversight of government SETIs, clearly defined roles for each set of institutions, and arrangements for evaluation of their performance and their contribution to national development.

The MCST was tasked with embarking "on a fundamental investigation into the governance and management structures of government-funded science and technology performing institutions" (pp19-20).

This section also considered three major inputs into policy-making. The first concerned the role of IT. The White Papers noted (p20): "South Africa currently lacks a national policy to facilitate the country's optimal integration into the global information society and outlining clear responsibilities, goals and targets. This is a serious defect in our overall innovation drive and must be remedied as soon as possible." Key policy issues identified in this regard included, among others, copyright and intellectual property; how local industries could "take full advantage of the R&D and technological development opportunities presented by the information community"; and how IT could "best be used to improve the growth and competitiveness of all South African businesses, especially SMMEs" (pp20-12).

The other two major inputs envisaged for policy-making were the results of the Research and Technology Audit and the Research and Technology Foresight Exercise, both of which DACST was carrying out at the time. The results of the Audit were to inform the Science Budget process and to generate data "on the distribution of national scientific capacity" to inform "the investigation into the structure of the government-funded elements" of the NSI (p21). The outcomes of the Foresight Exercise were envisaged primarily "to inform R&D investments by the public and private sectors"; government's "investments in R&D within the Science Budget"; and management of the Innovation Fund and the "system of support for research capacity building in the higher education sector" (ibid.).

This section also covered interactions between the S&T and other policies. In particular, it stated that the policy proposed in the White Paper on S&T was "specifically designed to reinforce the pillars of the Growth and Development Strategy" which had been adopted by Cabinet in late 1995 (pp21-22).

The section concluded with the issue of resource allocation, with a specific focus on the need for a Science Budget. The White Paper noted that, at the time, "budgetary decision-making within Government concerning expenditures on S&T [was] done on a partial basis, and only with a single-year perspective", and thus a Science Budget would "be an important tool for Ministers to use as they allocate resources to competing priorities [and] provide Parliament with a better overview of the range of government allocations in support of SET activities" (p22).

Regulatory policy

Two issues were addressed in this section. The first was aligning patenting regulations with international norms. Here, the White Paper referred to intellectual property, the collective term referring to "four types of intangible property, namely, patents, trademarks, copyrights and trade secrets" (p24). It noted that while no specific legislation was proposed in the White Paper, DACST would work with the dti"to establish how South African patenting regulations should be revised to best promote innovation" (ibid.). The second issue addressed pertained to promoting safety, health and the environment. The White Paper noted that, at the time, regulations in this regard were "dispersed throughout a multiplicity of Acts" and that what was required was a regulatory framework that was "simple and consolidated" (ibid.).

Financing (at the performance level)

The point of departure for the initiatives addressed in this section was the recognition that innovation went beyond S&T and that "excellence in S&T does not necessarily translate into innovation" (p25). Furthermore, the White Paper stated (ibid.): "In the past, policies designed to improve the S&T output of a nation have not recognised the importance of non-technological factors to the innovation cycle. As a result, S&T initiatives have often failed to deliver consistently and coherently against promises of economic growth and employment creation." Thus, the proposed initiatives in the White Paper were linked to the "functions of Government, industry associations and firms connected with the implementation of innovation programmes, and strategies for improving the efficiency and extent thereof" (ibid.). As such, the performance-level financing initiatives covered included the following:

- **The Innovation Fund:** Seen as a key measure for giving "effect to the concept of innovation, as opposed to S&T or R&D", the Innovation Fund was framed as offering "a new lead in encouraging and enabling longer-term, large innovation projects in the higher education sector (HES), government SETIs, civil society and the private sector" (p25). The principal objectives of the initiation of the fund related to: the reorienting of the historical allocation of resources "towards the key issues of competitiveness, quality of life, environmental sustainability and the harnessing of information technology"; funds for government SETIs to be awarded on a competitive basis; and "to promote increased networking and cross-sectoral collaboration" within the NSI.
- **Principles for funding R&D in the higher education sector:** This was to be based on "a coordinated system of grant financing of research" in higher education institutions (p26) and the finer details of the parameters of this arrangement are elaborated upon. Mention was also made of the responsibilities and institutional arrangements of the NRF in its various roles relating to grant funding.
- **Private sector funding:** It was noted that government policy with regard to private sector funding, and particularly that for SMMEs, was already addressed in a separate White Paper. The focus in the White Paper on S&T was on three dimensions:
  - **Procurement policy:** The rationale for the need for revisions to procurement policies, although not directly addressed in the White Paper on S&T,[10] was stated as follows: "The pro-active application of the purchasing power of the broad public sector is an important policy instrument for Government in order to promote technology and industrial development. A selective procurement policy has been applied in the past to give preference to local producers in selected industries and to provide measures to encourage local product design and development. Unfortunately, the policy did little to encourage the development of technological capabilities in industry and in some ways both limited and distorted product development" (p28).

10 Being addressed through initiatives of the Ministry of Finance and the dti.

– **Innovation Fund and SPII:** It was noted that an "inter-departmental committee will be established in order to align the objectives of SPII and the Innovation Fund" in recognition of the fact that: "Direct subsidy of such expenditure via the Innovation Fund and an expanded SPII … remains the only realistic option if incentives for private sector innovation are to be increased" (p29).

– **Tax incentives:** This subsection raised the issue of the CSIR playing the role of the certifying body (potential for a conflict of interests), calling for the re-examination of this arrangement, and referred to the proposed arrangements for indirect incentives via the Innovation Fund and SPII, noted above (p29).

Performance

With regard to the management and financing of government SETIs, the White Paper stated (p30): "The current management and financing system for SETIs in South Africa has some desirable features which should be retained or extended. Nevertheless, it does not meet many important criteria and needs to be amended in such a way that the new mechanisms do not obstruct their effective functioning." Three aspects were addressed in this regard:

- **A new management system for SETIs:** Government-owned or government-funded SETIs included state-owned enterprises, science councils and department-based institutes. The goals of the new management system included, among others (pp30-31): activities that "serve to advance national goals and priorities"; administrative structures that "are conducive to promoting a favourable climate for innovation"; a system of performance measurements via "a formal system of peer review, stakeholder input and efficiency auditing"; funding and financing systems that align with "generally accepted accounting practice"; and to "reduce the fragmentation of the existing system by introducing improved systems of coordination".
- **Policy principles for the funding of government-funded SETIs:** In order to address issues such as the inadequate financing of R&D performance and to address historical problems such as "fragmentation and lack of transparency of the existing system", the White Paper proposed a new management system for funding of government SETIs in relation to (pp31-32): budgetary support for research; contract support for the purchase of scientific or technological inputs; and grant support for research allocated on a competitive basis.
- **The process of institutional review:** In addition to the proposed investigation into the governance and management of SETIs by the MCST, the White Paper proposed that it was "equally imperative to develop a dynamic system in which the outputs from and outcomes of SETI activities are assessed within the context of current and projected future national needs and benchmarked according to best-practice criteria" (p32). Periodic reviews of SETIs should focus on: the contribution of the output of the SETI to the realisation of national goals or international commitments; the scientific quality of the outputs; and the quality of the management of the institutions. The NRF and the national facilities would also be subject to review.

In terms of **operational issues of government-funded SETIs,** the White Paper addressed seven needs (pp33-35): the replacement of input criteria by output criteria for the science councils; a unified framework for SETIs; the role of line departments; 'unfair competition' between science councils and the private sector in terms of government funding; reorientation of defence research; the role and functions of the Atomic Energy Corporation; and the linkage of government SETIs to postgraduate education.

The final section dealt with **promoting linkages between sectors and stakeholders**. The White Paper noted that various key matters "can only be addressed in the context of linkage" (p36). Such matters include: wasteful duplication of activities; fragmentation of effort; lack of coordination between institutions; diffusion of best-practice technology; increasing R&D investment in the private sector; lack of leadership to achieve national SET objectives; promotion of a performance culture; focus of activity; and making full use of the social sciences and IT in the NSI. It also noted the importance of the link between basic and applied research "with respect to real problem solving" (ibid.). As such, the White Paper drew attention to (pp36-37): the provision of mechanisms to link R&D output to practical use; linkages between firms; technology diffusion, with a specific focus on SMMEs; and international agreements.

Human resource development and capacity building

Speaking in more general terms about human resource development (HRD), the White Paper stated (p38): "HRD is dependent on a comprehensive strategy outlining coherent and integrated policies in a wide range of related areas, including economic, labour, education and training, and science and technology policy. Central to this approach is the belief that attempts at reforming an element of the system, for example, education and training, in isolation of developments in other policy areas and social institutions will not generate the desired outcomes." The White Paper distinguished between institutional and individual capacity-building, where the latter "involves the development of high-level skills, competencies, values and attitudes required for S&T development" and "addresses training, but also includes curricula and reward systems for a research career and fostering a supportive research culture" (ibid.).

The White Paper tied itself closely to the imperatives and intended outcomes of the Growth and Development Strategy in terms of HRD; in particular, "investing in people as the productive and creative core of the economy", and an HRD strategy that includes aspects to do with training, the restructuring of education and social partnerships (p38). Accordingly, DACST was assigned the responsibility of "bringing the perspective of S&T to each of these programmes" (ibid.).

The White Paper addressed HRD and capacity-building in a number of areas, including the following:

- Equity through redress: With reference to the imbalances and inequalities created by the apartheid system, and particularly the exclusion of black women and men from social, political and economic spheres, the White Paper stated (p39): "An effective HRD programme in science, engineering and technology is … vital to redress this imbalance, to improve our economic performance and to ensure the proper functioning of the NSI. Such a programme will have to address the consequences of past deliberate policies and practices that promoted racial and gender discrimination in HRD. Apart from the human rights issue, there is also the imperative for South Africa to optimise its productivity and economic performance to succeed in the global marketplace." As such, the White Paper stressed the need for "affirmative actions" and the importance of lifelong learning.
- Research capacity development at historically disadvantaged institutions (HDIs): Reference was made to the DACST programme "to obtain Official Development Assistance funding to establish or strengthen centres of excellence in research in HDIs", the objectives of which included (p39): to stimulate the development of S&T; to target women and black students in these fields of study; and to promote institutional change in keeping with the first two mentioned.
- HRD and capacity building at the national level: This section addressed national-level requirements to underpin strategies for HRD, as well as a focus on the specific areas of lifelong learning, and compulsory mathematics/science at pre-tertiary level.
  - With regard to the foundations for an HRD policy and its implementation, the White Paper noted that a national HRD and capacity strategy "must aim at building scientific, technological and managerial abilities and capacities at the individual, institutional and community levels", and that achieving this objective "would require an approach that promotes flexibility and trans-sectoral participation, the establishment of standards, accreditation and certification criteria, credit transfer and the redress of inequities"; the introduction of mechanisms to promote efficiencies and linkages to the GDS; as well as "a framework for sustainable implementation" (p40). The NQF and SAQA would be the central enabling mechanisms for this approach. In implementing the policy, the White Paper stressed the need for the relationship among institutions to be "organised so as to advance the GDS" (ibid.). This would involve, among others, that "government institutions, the private sector and other stakeholders must collaborate in determining the policies, planning and implementation of the HRD programmes", and that institutions were "brought into the process of policy making and development, planning, management, implementation and evaluation in a coherent way" (ibid.).
  - Referencing the tripartite discussions of the National Training Board and the 1995 White Paper on Education and Training, the White Paper contextualised the focus on lifelong learning in terms of the "disparities in skills and competencies evidenced in the labour market" as a "direct product of a segregated system of education and training" which had, among others, resulted "in an imbalance in the composition of graduates produced by institutions of education and training" (ibid.). Looking forward, the White Paper argued that the "ever-increasing technological content of competitive modern economies requires a society with lifelong learning as part of its standard norms, ethos and practices", and that "policymakers and decision makers in government, business and industry must integrate the lifelong learning ethos into the competitive strategy of the nation" (ibid.).

– The White Paper noted that the "comments received in response to the Green Paper have shown overwhelming support for maintaining compulsory mathematics and science up to the exit level (currently Gr 7) from the compulsory phase of education and training" and that these subjects would thus be contained in the General Education Certificate of the system proposed by the DoE (pp40-41).

- **Adult basic education and training:** The emphasis on ABET (regarded as a high priority) was aimed at addressing the discrimination and inequality created by the apartheid system by "furthering of the skills and career prospects of workers and the unemployed" and redressing "the exclusive 'youth' focus of schooling" (p41). The White Paper stated that the "future system must therefore make provision for lifelong-learning opportunities to serve a wide range of learners through structures that will be readily accessible and affordable" (ibid.). It pointed to the need for partnerships between the state, employers, labour, communities, funders and NGOs, as well as collaboration around funding support at provincial and local levels (ibid.)
- **Technology education:** The White Paper noted that given the "general acceptance that technological capability is central to contemporary society, has led many advanced and developing countries towards introducing technology education into the school curriculum", and that based on "the overwhelming support received in responses to the Green Paper for introducing technology education across the General Education system, DACST will assist the Department of Education in developing a technology education programme for schools" (p41).
- **Public awareness of S&T:** The White Paper pointed to "the potential of technology for improving the quality of people's lives" but noted that "disadvantaged populations in general and women in particular, especially those in rural areas, have little access to information about these technologies" (p41). It stated that a "campaign to promote awareness and understanding of S&T and of its importance will have two key elements" – promoting S&T literacy and promoting the power of S&T. DACST would drive the delivery of S&T public awareness programmes "in collaboration with consortia of institutions, including societies for the advancement of science, professional associations, academies of science, science museums and libraries, media (printed and electronic), educational institutions and private business" (p42).

Science and technology infrastructure

The final key initiative in the White Paper related to S&T infrastructure, which it defined as referring to national research facilities and services, libraries, regulatory frameworks, and to extended physical structures such as telecommunications networks – all of which were part of the overall public investment programme in infrastructure as outlined in the government's Macroeconomic Strategy document at the time (p43). This section of the White Paper covered the establishment, operation and maintenance of: information services; technical services; a system of awarding, recording and protecting IP; and major national facilities for research.

In terms of **information systems**, the White Paper pointed to government's role at the regulatory level, "developing flexible and responsive structures to deal with such a rapidly changing environment", as well as the need for government "to ensure the acquisition and effective use of up-to-date S&T information and access to international electronic information resources" (p43). Systems underpinning an effective national information system included telecommunications infrastructure, IT infrastructure, and an information architecture.

The White Paper noted that **libraries** played two important roles in the NSI: technical libraries as "an essential resource for research workers and technologists" (p43), and general libraries in terms of adult education and the public understanding of science (p44). As such, the White Paper highlighted the need for appropriate funding, regional sharing of resources, and investment in modern information technology. **Museums** "fulfil unique research and service functions, particularly in the taxonomic and even forensic sciences" (ibid.). The White Paper stated that "the role of our museums must be defined and encouraged", including their role in fostering public awareness of S&T.

The White Paper made brief reference to **statistical services, indicators and databases**, noting that it was "the function of Government to run data-gathering and statistical services such as censuses and economic and climatic indicators", and that the "involvement of Government in these activities is usually predicated upon the large costs involved, the fact that the statistics should be on the public domain or that privacy of personal information is relevant" (p44). It noted that the "Research and Technology Audit will result in a substantial data base which will need to be maintained and updated regularly" – a function that was to be undertaken by DACST (ibid.).

With regard to the establishment, operation and maintenance of **technical services**, the White Paper noted that while most measurement and calibration activities were conducted outside of government, "Government must provide the legislative framework for the national measurement system" (p44). The technical services that must be maintained at national level included measurement standards, calibration, product and service standards, quality and environmental management standards, and accreditation.

In terms of **awarding, recording and protecting intellectual property**, the White Paper noted that whatever regulatory system South Africa adopted in this regard, "there are certain requirements for the system administering the patents. In particular, search and retrieval capabilities should utilise modern information technology to reduce management costs and to promote compliance with international standards" (p45).

The White Paper mentioned the already-established **major national facilities (NFs) for research** – the National Accelerator Centre (NAC), the South African Astronomical Observatory (SAAO), and the Hartebeesthoek Radioastronomical Observatory (HartRAO). It noted that all three "could benefit human resource development and the scientific community as well as the wider public's perception of them by being involved in the formal tuition programmes of local universities" (p45). Looking forward, the White Paper stressed that "the future establishment of NFs must be motivated by national needs because such facilities consume substantial government resources", and that government should "be satisfied that proposals for new NFs have the broad support of the SET community" (ibid.). It outlined the main criteria for the establishment or evaluation of NFs, and highlighted ideas about possible new facilities.

The section concluded by addressing the matter of **scientific equipment**, noting that "[p]rovision should be made for the purchase and maintenance of costly items of research equipment not at the national facility level", and that these should be allocated by the NRF, taking into account: access by all researchers in the region, particularly those from HDIs; optimal placement with respect to concentrations of researchers in the relevant field; and a contribution in kind from the chosen SETI (p45).

In the following sections, we turn our attention to an analysis of the NRDS and TYIP.

1.3 The National Research and Development Strategy (NRDS)

1.3.1 Context and problem analysis

The NRDS starts with a problem analysis of the state of the South African system of innovation in 2002 by identifying the following six key problems:

1. **The termination of key technology missions** (especially in the military domain) by the apartheid government. This had led to a situation where GERD/GDP decreased from 1.1% in 1990 to 0.7% 1994. This decrease occurred exactly at the time when the NSI needed to expand to cope with the needs of 40 million people as opposed to just 5-6 million (i.e. the minority white population).
2. **New strategic challenges** related to human, economic and security issues. Specific mention was made of the need to respond adequately to new diseases (by implication HIV/AIDS). The conclusion was that the existing S&T capacity of the country at that time was not adequately placed to address these new challenges and was in fact losing ground.
3. The **stagnation of the human resources base** for S&T. An overwhelmingly white, male and aging scientific population was not being replaced by younger groupings more representative of the demographics of the country.
4. **Reduced levels of investment and performance by the private sector** in R&D which was the result of various factors related to globalisation.
5. **Inadequate intellectual property legislation and infrastructure**. New developments in biotechnology had increased the country's vulnerability with respect to the exploitation of our biodiversity, and inventions and innovations from publicly financed research were not effectively protected and managed.
6. **Fragmented governance structures**. Although research institutions had been reviewed and key performance indicators put in place, the roles of different departments in governance and in setting output targets for government research institutions were not clear or synergistic. From a budgetary perspective, there was no holistic view of S&T spending by government.

The central structural concept in the NRDS is that of the National System of Innovation (NSI). In adopting this as an organising principle, the NRDS sought to build on the introduction of this concept in the earlier 1996 White Paper. From an analysis of the characteristics of NSIs in various national contexts, two key high-level "goals" were proposed – which in contemporary terminology might be regarded as areas of impact for the NSI – namely: (1) quality of life, and (2) growth and wealth creation. Thereafter, the strategy outlines three key "processes" that serve the goals, and which might approximate to outcomes in today's language, these being:

- ('Improved') business performance,
- Technical progress (innovation and improvement), and
- Effective and growing SET human capital.

These "intermediate processes" or outcomes were dependent on the "fundamental activities related to the acquisition, generation and application of knowledge", which might be approximated to outputs or drivers in contemporary performance management and planning rhetoric, namely:

- Imported know-how,
- Current R&D capacity, and
- Future R&D capacity.

1.3.2 Theory of change: Goals and expected outcomes

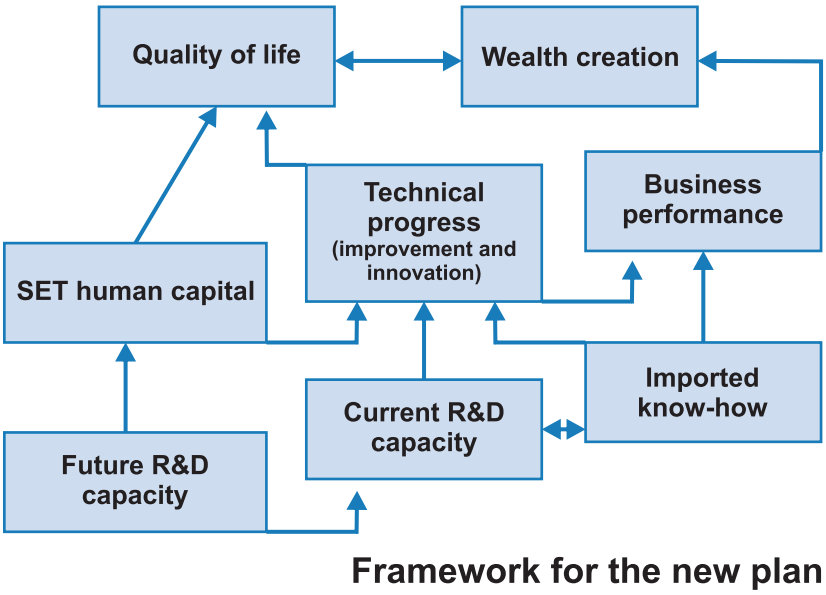
The brief narrative below is presented in the NRDS to explain the relationship between these three layers of concepts (DST, 2002: 28). The narrative presented to clarify the "logical indicator framework" can be read as a 'draft' theory of change.

> *A diagram depicting this framework and showing the most important relationships between its elements appears in Figure 1. Modern economies require all these elements to be present and growing. This framework is a representation of the National System of Innovation (NSI). The two major outcomes required from R&D and innovation are increased wealth and quality of life. There is incontestable evidence that this process requires ongoing public sector investment. At least 30% of R&D spending in large integrated developed economies (population >60 million) is made by the government – usually of the order of 0,4 to 0,5% of GDP. In effective smaller nations, government participation in non-defence R&D is higher (typically 0,6 to 0,75% of GDP). Some knowledge-based economies have government spending of closer to 1% of GDP.*
>
> *This spending creates future R&D capacity and partially sustains SET human capital and the current R&D capacity of the economy. The major functions of the SET human resources and R&D are to drive improvement and innovation in the economy (as well as being involved in smart adoption of imported know-how). Improvement and innovation directly impact quality of life (for instance in the health care sector) and business performance (e.g. through new products and processes). In developed countries more than 50% of economic growth is attributable to technical progress.*

From a financing perspective, governments can target their investments in three focus areas to achieve the desired outcomes:

- *The creation of a critical mass of SET human capital and a corps of researchers and future researchers;*
- *The stimulation and enhancement of innovation and improvement (technical progress) based on new technology and innovation missions and imported know-how; and*
- *The stimulation of enhanced entrepreneurship and enterprise development through targeted creation of venture capital and provision of fiscal incentives for private sector R&D.*

Figure 2: The logical indicator framework of the NRDS (From capacity to outcomes – how R&D impacts economic growth and quality of life")



Source: DST (2002: 26)

It is clear from the narrative – and read together with the diagram – that the investment in R&D should have been explicitly included in the diagram (at the bottom). The (reconstructed) theory of change would read as follows:

Box 2: (Re)constructed theory of change of the NRDS

IF a country invests sufficient funds in R&D[11]
THEN it will (can) sustain the current SET capital in the country AND the current R&D capacity
AND create/build the future R&D capacity.

IF the SET human resources and R&D are utilised efficiently
THEN these should drive improvement and innovation in the economy
AND lead to the smart adoption of imported know-how.

IF there is sufficient technology innovation and growth
THEN more wealth will be created by South African businesses and enterprises
AND the quality of life of South Africans will improve.

1.4 The Ten-Year Innovation Plan (TYIP)

1.4.1 Context and problem analysis

The TYIP takes as its point of departure "government's broad socioeconomic mandate – particularly the need to accelerate and sustain economic growth – and (builds) on the foundation of the national system of innovation (NSI). It recognises that while the country's science and technology system has taken important strides forward, there is a tremendous gap between South Africa and those countries identified as knowledge-driven economies" (DST, 2008: vii). It is this analysis that informs the central tenets of the plan that (1) the gap needs to be closed, and (2) "the NSI must become more focused on long-range objectives, including urgently confronting South Africa's failure to commercialise the results of scientific research, and our inadequate production (in both a qualitative and quantitative sense) of knowledge workers capable of building a globally competitive economy" (ibid.).

[11] Arguably at least 1% of GDP.

A novel aspect of the TYIP was the introduction of five so-called 'grand challenges'. The stated purpose of introducing these grand challenges as a conceptual framework was that they "address an array of social, economic, political, scientific, and technological benefits" and "are designed to stimulate multidisciplinary thinking and to challenge our country's researchers to answer existing questions, create new disciplines and develop new technologies" (ibid.: viii). Each of the grand challenges is outlined in a narrative, the details and scope of which vary quite widely, but in each case a set of "outcomes" is presented, which are either quantifiable or categorical (i.e. they are either achieved or not).[12] While it is not explicitly or systematically stressed, it is implied that each grand challenge would be outlined in a separate set of detailed strategic programmes and plans, which limits the detail provided in the TYIP. The grand challenges are:

- Farmer to Pharma
- Space Science and Technology
- Energy Security
- Global Change, and
- Human and Social Dynamics.

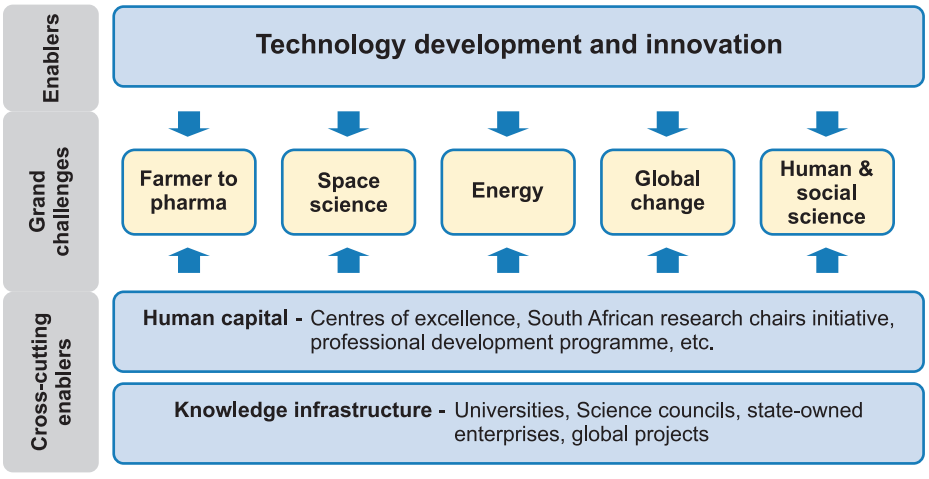
Thereafter, the document sets out three cross-cutting macro-level imperatives, these being:

- Innovation as a national competence
- Human capital development and knowledge generation,
- Science and technology across government[13]

1.4.2 The TYIP theory of change

Following a discussion of the general relationship between research output, innovation and socio-economic development, the plan introduces the five grand challenges. The underlying rationale of the grand challenges is that they focus on areas in which South Africa is seen to have specific advantage and, more especially, will assist the country in its transition to a knowledge-based economy. The latter would be achieved by driving development of these areas through three "enablers" – namely, the development of human capital, the provision of knowledge infrastructure, and measures to promote technology development and innovation. The plan depicts this 'conceptual framework' in the diagram below.

Figure 3: Link between enablers and the grand challenges in the TYIP



Source: DST (2008: 9)

If anything, it is more difficult (compared to the NRDS), to (re)construct a coherent theory of change for the TYIP. The reasons for this are already evident in the sections above. The TYIP does not make any explicit reference to the two main impact domains that formed the core of the NRDS, namely wealth creation and

[12] An example is the establishment of a specific institution. This is neither quantitative nor qualitative, but categorical: the institution is either established or not.

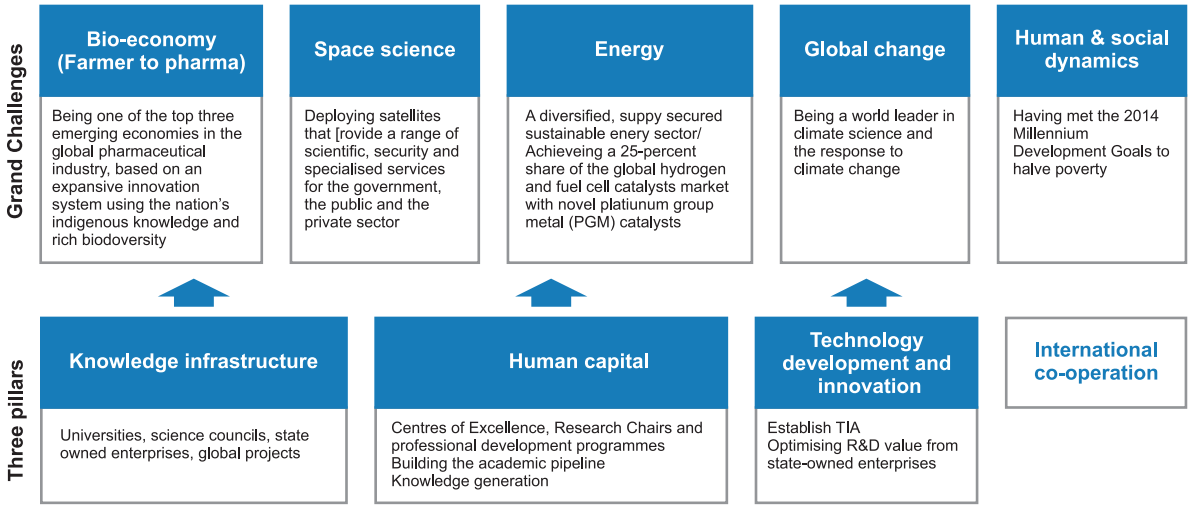
[13] The TYIP refers to "governments", i.e. the plural term. We assume this is a typographical error.

quality of life. Instead, the focus has shifted towards a different overarching goal: to become a (competitive) knowledge economy. This is captured very clearly in the following statement: "The purpose of this Ten-Year Innovation Plan is to help drive South Africa's transformation towards a knowledge-based economy, in which the production and dissemination of knowledge leads to economic benefits and enriches all fields of human endeavour" (ibid.: vii). Four drivers of progress toward a knowledge-based economy are identified: (1) human capital development, (2) knowledge generation and exploitation (R&D), (3) knowledge infrastructure, and (4) enablers to address the "innovation chasm" between research results and socioeconomic outcomes (ibid.).

These statements are followed by a "Vision statement for 2018". This vision statement is contrasted with "many short- and medium-term plans, which amount to an aggregation of current activities" (ibid.: 4). Instead, the plan sets out a different point of departure, namely that "it begins with where South Africa needs to be a decade from now – an agreement on what we will have accomplished by 2018. These strategic outcomes are identified as the 'grand challenges', and we are confident that the nation, and our entire science and technology system, will rise to the occasion" (ibid.).

On the basis of this narrative, we have constructed a theory of change for the TYIP as per Figure 4 below.

Figure 4: Reconstructed theory of change for the TYIP



In monitoring and evaluation practice, it is assumed that a 'plan' follows a 'strategy' and would typically be much more concrete and specific about expected outputs, outcomes and measures to assess these. But this is not the case. The rhetoric of the TYIP is less definitive than that of the NRDS, and more open-ended in many respects, freely mixing qualitative assessments or analyses of particular aspects of the NSI with comments on its desired state or possible developments, without elevating these to explicit strategic imperatives or priorities. In the following two chapters we analyse and discuss in more detail the 'logics' of each of these documents.

CHAPTER

2

FORMATIVE ASSESSMENT OF THE NRDS

2.1 Introduction

In this and the following two chapters we present the results of our assessments of the NRDS and TYIP, respectively (Level 1 analysis). Chapters 2 and 3 are devoted to a discussion of the formative assessments of these two documents, with the emphasis on clarificatory evaluation and evaluability assessment. Chapter 4 presents a discussion and assessment of the outcome/impact indicators listed in these two documents and their relative achievement.

The six formative assessment questions (see Box 3) are split between three clarificatory evaluation criteria (1-3) and three evaluability assessment criteria (4-6). In theory these criteria should be applied in equal measure to a strategy or plan. But one could argue that the evaluability assessment criteria (4-6) are strictly speaking only applicable to the assessment of a plan (i.e. the TYIP). We decided to apply all six criteria to both documents; however, we have been more 'lenient' in our scoring of the NRDS in terms of the evaluability criteria.

Box 3: Formative assessment questions

1. Has the strategy or plan been designed on the basis of a proper problem or needs analysis?
2. Are the goals and objectives of the strategy or plan clear and unambiguously formulated?
3. Does the strategy or plan take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success?
4. Is the strategy or plan sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it?
5. Is the strategy or plan sufficiently clear about the resources (especially funding and infrastructure) that would be required to implement its various interventions to optimise success?
6. Does the strategy or plan specify how its progress and ultimate achievements and impact will be monitored and evaluated?

We utilise a colour-coded rating system, as highlighted in the legend below. This is followed by an elaboration of the basis upon which we have made our assessments and a discussion of the results.

To a large extent addressed

Moderately well addressed

Poorly addressed

2.2 The NRDS and problem analysis

Q1: Was the NRDS designed on the basis of a proper problem or needs analysis?

Our assessment ('to a large extent addressed') is based on the fact that the NRDS begins with an analysis of the state of the South African NSI at the time, and clearly identifies six critical challenges or problems that need to be addressed:

1. Inadequate and declining levels of public investment in R&D.
2. Inadequate and reduced levels of investment and performance by the private sector in R&D.
3. New strategic challenges that the existing S&T capacity needs to address.
4. The stagnation of the human resources base for S&T.
5. Fragmented governance structures; lack of role differentiation between STI-related government departments and agencies; and no holistic view of S&T spending by government.
6. Inadequate existing IP legislation and infrastructure that could compromise the protection of South African IP.

The NRDS then proceeds to identify 10 strategic responses or objectives[14] to address these challenges. Figure 5 below presents a visual summary of the relationship between the key problems identified by the NRDS and how the document sets out the strategic responses or objectives that would need to be implemented to address these.

Figure 5: Challenges and strategic objectives in the NRDS

Challenges (2002)	NRDS	Strategic Objectives
Reduced public investment in R&D		1. The new R&D Strategy depends on doubling governance investment in science and technology over the next three years, with more gradual increase thereafter.
Reduced private sector investment in R&D		2. Put in place venture capital stimulation and fiscal incentives to encourage and enhance private sector participation - the responsibility to be located at the dti and Industrial Development Corporation.
The STI faces new strategic challenges		3. Consolidate existing technology missions and establish new technology missions (eg. Technology for Poverty Reduction) 4. Establish FTI to operate as a knowledge-based financing agency concentrating on innovation within each of the technology missions. It will fund innovation across the public and private sectors, and across the value chain form concept to market-through, with a key focus on high-cost ad market acceptance stages through commercialisation, incubation and diffusion.
Stagnating human resources for S&T base: S&T capacity is "losing ground"		5. Expand HR base through increase in female and black scientists 6. Attract more local talent into science (science awareness and promotion initiatives) 7. Attract more foreign talent through increases international agreements/attracting post-doctoral fellows to SA 8. Ensure the pursuit of excellence in science (SA science must be/remain world-class)
Ineffective S&T governance		9. DST to coordinate a coherent performance management system for all government-owned laboratories and to have direct responsibility for five cross-cutting institutions
Inadequate IP protection		10. Develop the national capacity to manage intellectual property (especially interlectual property derived from publicity financed research). Establish an IPO fund und the Innovation Fund and IP database

[14] The 'strategic responses' are often also referred to as 'strategic objectives'. We will use the term 'strategic objective' as a more general term rather than the term 'strategy' when referring to these 10 responses. The reason is that the 10 strategic objectives are not all formulated explicitly as (identifiable) strategies or even as 'strategic objectives'. We will comment on this point in our detailed discussion of each response.

As noted above, in some cases in the NRDS document the discussion under a strategic objective identifies a specific 'subsidiary' intervention or mission to be developed and implemented to give expression to a strategic objective. This is especially the case with regard to strategic objective 3 where four technology missions are mentioned by name, and with regard to strategic objective 8 where four science missions are identified. In other cases, a specific suggestion or proposal is made (e.g. establish a Foundation for Technological Innovation or develop a tax incentive scheme). However, in others, only passing references are made either to existing programmes or initiatives (e.g. around science promotion) or to specific actions that need to be taken (better co-ordination across government departments around S&T).

2.3 NRDS goals and objectives

Q2: Were the goals and objectives of the NRDS clear and unambiguously formulated?

We have scored the NRDS as 'moderately well addressed' on this criterion. As indicated in the previous chapter, the NRDS presents what is best described as an implicit theory of change. In our discussion of this theory of change we pointed to some conceptual ambiguities, as well as poor linkages between outcome/impact statements and indicators. In general, our assessment was that despite the (admirable) attempt to formulate a theory of change, it does not meet the criteria of good practice in intervention design. Having said that, to their credit, the authors of NRDS did formulate a number of 'strategic objective' statements which can be loosely linked to the theory of change. The NRDS is not entirely consistent in this endeavour. In some cases, an explicit strategy or intervention or programme is identified to address a specific challenge; in other cases only passing and incidental references are made to possible actions to be taken. This is illustrated in Figure 6 below where we have mapped the strategic objectives to subsidiary strategies and interventions where these are explicitly referenced in the NRDS. We also indicate where no explicit strategy or intervention is mentioned.

Figure 6: Subsidiary strategies/interventions mapped to the strategic objectives identified in the NRDS

STRATEGIC OBJECTIVES	STRATEGIES OR INTERVENTIONS IDENTIFIED
1. The R&D Strategy depends on doubling government investment in S&T over the next three years, with more gradual increases thereafter	No specific intervention identified
2. Put in place venture capital stimulation and fiscal incentives to encourage and enhance private sector participation - the responsibility to be located at the dti and IDC	No elaboration on venture capital stimulation programme; establish R&D Tax incentive scheme
3. Consolidate existing technology missions and establish new technology missions	Consolidate existing technology missions (ICT, biotechnology, advanced manufacturing), develop new mission (Technology for Poverty Reduction)
4. Establish FTI to operate as a knowledge-based financing agency concentrating on innovation within each of the technology missions	Establish the FTI (TIA)
5. Expand HR base through increase in female and black scientists 6. Attract more local talent into science (science awareness and promotion initiatives) 7. Attract more foreign talent through increased international agreements /attracting post-doctoral fellows to SA	No explicit mention to any specific HRD strategy. Only ''disjunctured'references to the establishment of a 'women in science'programme, the desirability of establishing a CoE programme, and the importance of international agreements
8. Ensure the pursuit of excellence in science (SA science must be/remain world-class)	Identified four 'science missions': astronomy, palaeosciences, IKS, Antarctic and marine science
9.DST to coordinate a coherent performance management system for all government-owned laboratories and to have direct responsibility for five cross-cutting institutions	Suggestions about standard governance/reporting framework, better coordination across departments etc. specific intervention identified
10. Develop national capacity to manage IP (especially intellectual property derived from publicly-financed research)	Establish an IP office, fund and database

2.4 Assessment of risk

Q3: Did the NRDS take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the strategy were aware of potential risk factors that may impact negatively on the achievement of strategy's objectives?

Although not discussed or elaborated upon in any detail, the authors of the NRDS did indicate that the ultimate success of the strategy is dependent on a number of conditions being met, thus our assessment of 'moderately well addressed'.

With regard to expenditure on R&D, the NRDS acknowledges that current (at the time) government expenditure on R&D – which was around 0.7% of GDP – was inadequate and that the strategy itself "depends on doubling government investment in science and technology over the next three years, with more gradual increases thereafter" (DST, 2002: 17).

The authors of the NRDS also expressed the concern that there was insufficient coordination of existing funding instruments – especially related to technology and innovation funding – hence the proposal about the establishment of an FTI (later TIA).

2.5 Agency and assignment of responsibility

Q4: Was the NRDS sufficiently clear about agency and locus of responsibility for the specific subsidiary strategies and interventions that are included in the document; i.e. is it clear who would take responsibility for the implementation of specific strategies and be accountable for their outputs, outcomes and impact?

Table 1 below lists the instances in the NRDS where reference is made either explicitly or at least indirectly to the responsible department or agency for a specific intervention.[15] Based on this evidence, we have assigned a rating of 'moderately well addressed' to the NRDS (i.e. agency specified in parts).

Table 1: Instances of agency identified in the NRDS

Strategy or intervention	Agency specified
Innovation pillar	
Establish the Foundation for Technological Innovation	*This function could be initiated in the Department of Science and Technology and developed to the point where its ultimate institutional form could be finalised. (p38)*
S&T for poverty reduction (social innovation)	No agency specified; except: *The increased recognition of the crucial role of technology in poverty reduction and sustainable development must be understood in terms of the creation of human capital (see centres of excellence below) … (p44)*
New technology platforms (biotechnology and ICT)	Biotechnology: • National Biotechnology Strategy (2001) already underway • The management of this new platform will be transferred to the Foundation for Technological Innovation when it is formed (p44) ICT: No agency specified

[15] Direct quotations italicised.

Strategy or intervention	Agency specified
Innovation pillar	
Technology for advanced manufacturing	No agency specified; except: *Knowledge intensity is having a direct impact on the advanced sectors of the manufacturing industry, and many of these industries, such as the automotive industry, are establishing integrated value chains as described by the Department of Trade and Industry's most recent strategy document.* (p46) – presumably the dtiDTI's Integrated Manufacturing Strategy
Technology and knowledge for and from resource-based industries	No agency specified.
Strengthened programmes to support innovation	No agency specified; except: The current pilot and roll-out programmes for technology diffusion and business incubation need to be strengthened. The GODISA and Tsumisano Programmes have shown good early promise, but are funded partly from ODA. Action must be taken to link such programmes, and SPII, and PII and the Manufacturing Advisory Centres into a more holistic programme of innovation support. (p47)
Human capital pillar	
Support of knowledge generation through basic science	No agency specified but presumably assigned to the NRF
The need for a new generation of scientists	No agency specified; but: • Re improving matric pass rates in mathematics and science – reference made to initiatives by Department of Education (p55) • National Research Foundation is establishing mentoring schemes and funding increasing numbers of black postgraduates. (p55) Re women and SET: • Reference made to CoEs to put in place strong gender-inclusive policies (p55) • The formation of the Women's Reference Group in Science and Technology will strengthen women-led initiatives in all phases of participation in science and technology, from school to career achievement. (p56)
Centres and Networks of Excellence	No agency specified.
Strengthening international S&T networks and connections	Only reference to agency in relation to 'Attracting talent to South Africa': *This will require specific joint planning between the Department of Science and Technology, the Department of Home Affairs and the Department of Education to ensure that effective measures are in place.* (p59)
Effective government pillar	
Alignment with the policy objectives of government	No agency specified; but general reference to 'government' needing to regularly review the research landscape and institutions in terms of desired outputs, outcomes and impacts (p62)
Mandates and responsibilities of different government departments	No agency specified.
R&D across government	DST to be responsible for: • *Publishing and annually updating a three-year R&D Plan "in sync" with the MTEF, capturing its R&D vision as well as key targets and investments (p64)* • *basic risk management assessment for technology, the national foresight capacity and the integration of individual budgets to produce an aggregate national research and development budget (p65)*

Strategy or intervention	Agency specified
Effective government pillar	
	• *A standard governance/reporting framework for all institutions with a strong R&D mandate (p65) (also to be administered by DST)* • *assemble all inputs into a Science and Technology Budget, and through this instrument advise Treasury, the Cabinet and Parliament of the important dynamics in the system (p65)* • *advise other departments of risks associated with funding and outputs from institutions within the system (p65)* respective line departments will set R&D goals and budgets for institutions reporting to them (p65)
Responsibilities for technology functions across government	• Basic and thematic research is funded by the Department of Science and Technology via the National Research Foundation and by the DoE in terms of formula-based research funding to higher education institutions. Other departments such as the DoH also play a role through the MRC and the ENHR frameworks. (p65) • Innovation and technology development and diffusion funding is widely spread across government, with the dti, the Department of Science and Technology, NDA, Defence, the DME, DWAF, DEAT, Health and several other departments all playing a role. (p65) • Industry sector strategies and venture capital programmes are largely the responsibility of the dti, although other departments do play subsidiary roles. (p66) • dti should take responsibility for venture capital programmes or tax treatment of private sector R&D (p66)
Intellectual property	• This indigenous knowledge process is articulated with the negotiations on the Convention on Biological Diversity, which is managed by the Department of Environment Affairs and Tourism. (p68) • A working group of government departments impacted by, or relevant to, indigenous knowledge and intellectual property issues meets on a regular basis to respond to changes in this dynamic domain. (p68) • A dedicated fund to finance the securing of intellectual property rights resulting from publicly financed research and development, when this is in the national interest, should be established. The management of this fund should become one of the activities of the Foundation for Technological Innovation. (p69) • DST to develop a national database of intellectual property that arises from publicly financed research (p70)
Private sector interventions	• *It is proposed that the dti be given a mandate in consultation with SARS and the Treasury to pursue the development of tax incentives to strengthen the attractiveness and affordability of R&D in the South African setting relative to countries with which we trade and compete. (p71)* • Re provincial innovation initiatives: *There is a need to ensure proper coherence of the initiatives at national level. This role can be undertaken by the proposed Foundation for Technological Innovation as part of its function to support and facilitate innovation.* (p71) • Re venture capital: *There is a more specific need for seed and early-stage venture capital for high-technology businesses and the Department of Science and Technology will engage with the dti to develop this domain.* (p72)

Strategy or intervention	Agency specified
Financing	
	• The FTI would not itself undertake innovation activities – such as later stage research and development, product development, business incubation and so on - but would finance and provide foresight and other direction-setting capabilities for these activities. (p40)
	• Figure 8 shows the increased finance needed to achieve the strategy. The new resources are dominantly dedicated to the human capital and transformation aspects of the strategy and the innovation financing, which is intended to create a mostly new function within the system of innovation. The phasing is intended to indicate the rate at which the system can respond to new inputs. This has been demonstrated over recent years by increases in, for instance, the MRC financing, which led to positive growth in both public financing and contract income. The phasing and implementation will be monitored by the Department of Science and Technology to ensure optimal and effective use of resources to achieve the strategy. (pp74-75)

2.6 Resources for optimal impact

Q5: Was the NRDS sufficiently clear about the resources (especially funding) that would be required to implement its various interventions to optimise success?

Q5: Was the NRDS sufficiently clear about the resources (especially funding) that would be required to implement its various interventions to optimise success?

The strategy devotes an entire chapter to the question of finance – at what level the various priorities, imperatives and initiatives need to be funded, and how such funding ought to be structured. While some macro-level financial projections extended beyond the Medium Term Expenditure Framework (MTEF) period of three years, most were projections for the 2002/03 or 2003/04 MTEF period.

An analysis of whether the specific levels of investment stipulated in the document were achieved or not seems spurious, given the massive inflationary and baseline increases to the DST and general S&T budget since then. Moreover, it is not always clear whether the amounts listed were new funds required beyond the 2002/03 baseline, or constituted the required baseline. However, in a few instances proportional changes or trends in proportional expenditure are stated, and these might reasonably be considered as targets in the context of this review of progress against the NRDS. Where relevant, such specific objectives or targets are listed in Table 2 below.

The table lists the instances in the NRDS where reference is made either explicitly or at least indirectly to budgets and estimated funding for identified interventions.[16] Based on this evidence, we have assigned a rating of 'moderately well addressed' to the NRDS (i.e. budgets and estimated funding for interventions specified in parts).

Table 2: Instances of budget estimates for interventions identified in the NRDS

Strategy or intervention	Budget estimates
Innovation pillar	
Funding for technology missions (p75)	*The financing requirements will form the core budget of the Foundation for Technological Innovation, which would also develop an operational budget for each of the programme areas and their support structures:* • *Technology and innovation for poverty reduction (R150 million)* • *Technology and innovation for advanced manufacturing and logistics (R125 million)* • *Technology and knowledge to leverage resource-based industries (R90 million)* • *New technology platforms for South Africa (R300 million) (biotechnology and ICT)*

[16] Direct quotations italicised

Strategy or intervention	Budget estimates
Innovation pillar	
Travel grant programme (p75)	A committed fund for global technology sourcing for SMMEs and BEE companies when the technologies are not available in South Africa, (R60 million).
Intellectual Property Fund (p76)	*The current expectation is that this fund will be a programme within the Innovation Fund and it will secure its financing from the Innovation Fund structures based on a full needs analysis.*
Strengthen Innovation Fund (p76)	*The Innovation Fund has not had the rate of growth intended in the original policy development. New financing will be required to put this back on track and be able to create capacity to establish the programme to secure IP from key publicly financed research that meets the criteria. The new financing required in the third year is R50 million.*
Strengthen technology diffusion (GODISA, TSUMISANO) (p76)	*These programmes are already developing a good track record and they can therefore be strengthened to increase their scope and impact. This requires additional financing over and above the current levels and links strongly to the required differentiation of the Technicons from the university structures as contained in the National Plan for Higher Education.*
Human capital pillar	
Centres of Excellence (p76)	*After three years, the funding required for this programme will be R150 million, starting with R50 million in the first year.*
NEPAD/SADC Networks and Collaboration (p77)	*Three types of financing are required: network/programme development, programme financing and institutional support, to initiate activities in other countries. This programme will require R41 million of new finance in the third year.*
Global science networks and collaboration (p77)	*After the third year the new finance requirement will be R42 million.*
Science and technology equipment (p77)	*New financing for large R&D equipment was requested a number of years ago. A small allocation (R14 million) was given for this purpose. Although the Department of Science and Technology has introduced stringent conditions for these equipment grants (large equipment, multi-institutional support, high potential for training and research, and use in a limited set of focus areas) the scheme is heavily over-subscribed. It is necessary to significantly increase this programme, as most equipment is sourced overseas (usually purchased in Dollars or Euros), equipment is a critical success factor in both biotechnology and ICT research as well as the chemical and physical sciences, and the ability of our scientists to be excellent globally is linked to quality of equipment. After the third year R90 million will be required, but this programme can be fast-tracked, based on our current experience, and therefore R60 million is required in the first year.*
Science Focus Areas (pp77-78)	*The new financing over and above current financing is indicated for the third year of this strategy:* • *Astronomy and Earth Observation R6 million* • *Indigenous knowledge R5 million* • *Bioscience/bio-resources R15 million* • *Paleo-world R20 million* • *Antarctic, Islands and Oceans R44 million* • *Total New Financing R100 million*
Public understanding and engagement activities (p78)	*This programme would cost R30 million in year three.*

Strategy or intervention	Budget estimates
Effective government pillar	
Core financing for Research Councils (p78)	No specific numbers given; only mention that a number of Councils require increases in core financing to assist with transformation, renewal of their research infrastructure and related issues.
National Risk Management and Foresight (p79)	In the third year, the financial requirement for this new activity will be R60 million (R20 million in the first year) with an approximate split of 50% foresight/ technology road-mapping and technology assessment, and 50% for science-based disaster prediction and intervention.

2.7 Monitoring and evaluation

Q6: Did the NRDS specify how its progress and ultimate achievements and impact would be monitored and evaluated (including indicators, targets and evidence of achievement)?

The NRDS includes relatively few indicators in the general text, over and above the 'indicators' specified in its theory of change diagram (see Chapter 1 above). In particular, it presents two tables of indicators relating to research and technology enablers, and investment and outcomes. The content of the two tables are combined in Table 3 below. On the basis of these scant references to indicators, we have given the NRDS a rating of 'poorly addressed or not addressed at all'. In mitigation, one could point out that the demand for monitoring and evaluating of public sector programmes and initiatives in the early 2000s was not as salient and 'pervasive' as today. The government-wide M&E framework was only adopted in 2005 and the DPME established in 2010. Furthermore, it should be acknowledged that NACI started tracking the indicators listed in the NRDS and the TYIP in its annual indicators reports from 2015 onwards.

Table 3: Specific indicators listed in the NRDS

Indicator/target	1990	Current (2002)	2012
Research and technology enablers			
Matriculants with university exemptions in Maths and Science	Not available	3.4%	7.5%
Proportion of SET tertiary students (% of all tertiary students)	20%	27%	30%
SET students (% of total age cohort)	6%	3.4%	12%
Global share of research outputs	0.8%	0.5%	0.7%
Number of SET practitioners per 10 000 of workforce	Not available	7	11
Investment and outcomes			
Economic growth attributable to technical progress	Not available	10%	25-30%
High and medium-tech exports	Not available	30%	40%
Number of SA originated US patents	100	100	>200
Government civilian R&D as a proportion of GDP	0.36% estimate	0.29%	0.6%
Government R&D expenditure/GDP	0.48%	0.36%	0.66%
Intellectual property net cost to SA (copyright and royalties)	R200 million	R800 million	Improve ratio
Internet hosts per 1 000 people	0	8.4	64
Telephone density per 1 000 people	87	270	700

Source: Combined from Table 1 (p32) and Table 2 (p33) of the NRDS

2.8 Concluding observations about the NRDS

The strengths of the NRDS are:

- The clear link between its strategic objectives and the problems it identified in the South African STI system in 2002.
- A relatively good mapping of interventions to these objectives (although not explicitly so in all cases).
- Moderately good indication of the responsible agents for implementation as well some indications of estimated funding allocations. However, too little consideration is given to linkages and coordination between departments and agencies tasked with implementing related strategies (the best example of this is the discussion around the human resources strategy).

The weaknesses of the NRDS are:

- Insufficient attention is given to developing a well-constructed and explicit theory of change.
- Listing and description of outcome statements, targets and indicators is seriously deficient.

On the basis of these assessments, the final scorecard of the results of our formative assessment of the NRDS is presented in Table 4 below.

Table 4: NRDS formative assessment scorecard

Clarificatory or design evaluation questions	
1. Was the NRDS designed on the basis of a proper problem or needs analysis?	
2. Were the goals and objectives of the NRDS clear and unambiguously formulated, and was there an explicit theory of change which stipulates how (through which interventions, programmes, and initiatives) the expected outcomes and impact of the strategy will be achieved?	
3. Did the NRDS take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the strategy were aware of potential risk factors that may impact negatively on the achievement of strategies objectives?	
Evaluability assessment	
4. Was the NRDS sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it; i.e. is it clear who would take responsibility for specific strategies and be accountable for these strategies?	
5. Was the NRDS sufficiently clear about the resources (especially funding) that would be required to implement its various interventions to optimise success?	
6. Did the NRDS specify how its progress and ultimate achievements and impact would be monitored and evaluated (including indicators, targets and evidence of achievement)?	

CHAPTER 3

FORMATIVE ASSESSMENT OF THE TYIP

As with the formative assessment of the NRDS, the legend below is applied to our assessment of the TYIP. The summary formative assessment scorecard is following by a discussion and elaboration.

- To a large extent addressed
- Moderately well addressed
- Poorly addressed

3.1 The TYIP and problem analysis

Q1: Was the TYIP designed on the basis of a proper problem or needs analysis?

The TYIP takes as its point of departure "government's broad socio-economic mandate – particularly the need to accelerate and sustain economic growth – and (builds) on the foundation of the national system of innovation (NSI). It recognises that while the country's science and technology system has taken important strides forward, there is a tremendous gap between South Africa and those countries identified as knowledge-driven economies." The fact that it is recognised that South Africa was lagging behind other knowledge-based countries relates to two other problems that were also identified: the country's failure to commercialise the results of scientific research, and the inadequate production of knowledge workers capable of building a globally competitive economy. On this question we have rated the TYIP as 'moderately well addressed' as reference is made to the OECD's 2007 review of innovation policy in South Africa and its assessment of the country's system of innovation.

3.2 TYIP goals and objectives

Q2: Were the goals and objectives of the TYIP clear and unambiguously formulated?

There is no dedicated discussion in the TYIP of specific strategic objectives, although there are many references to the plan's objectives or purpose embedded in the narrative. At the highest level, the Foreword by the Director-General (DST, 2008: vi) states that "the Plan's objective is to ensure that government investment in scientific research not only strengthens the effectiveness of our National System of Innovation, but also yields tangible socioeconomic benefits for our country."

In the Executive Summary it is stated that the "purpose" of the TYIP is "to help drive South Africa's transformation towards a knowledge-based economy" (ibid: vii), which in turn will be "driven" by the four elements (drivers) mentioned above.

The best statements of programme goals and objectives in the TYIP are found in its discussion of each of the grand challenges. Figure 7 below presents these objectives/outcome statements for each of the grand challenges. Although most of the statements remain very broad, they are sufficiently clear to warrant a rating of 'moderately well addressed'.

Figure 7: Strategic objective/outcome statements for each of the grand challenges in the TYIP

GRAND CHALLENGES	STRATEGIC OBJECTIVES
Farmer to Pharma (Bio-economy)	South Africa must become a world leader in biotechnology and the pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base
Space Science and Tecnology	South Africa should become a key contributor to global space science and technology, with a National Space Agency, a growing satellite industry, and a range of innovations in space sciences, earth observation, communications, navigation and engineering
Energy Security	South Africa must meet its medium-term energy supply requirements while innovating for the long term in clean coal technologies, nuclear energy, renewable energy and the promise of the "hydrogen economy"
Global Change	South Africa's geographic position enables us to play a leading role in climate change science
Human and Social Dynamics	South Africa should contribute to a greater global understanding of shifting social dynamics, and the role of science in stimulating growth and development

3.3 Assessment of risk

Q3: Did the TYIP take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the plan were aware of potential risk factors that may impact negatively on the achievement of the plan's objectives?

At various points in the narrative, reference is made to key prerequisites, which in many cases are not in place. Unfortunately, the document is silent on how to take these absences forward. A good example can be found in the concluding section where it is acknowledged that the "implementation of the plan has a number of prerequisites. These include state-of-the-art infrastructure, modern laboratories and research institutions, an NSI that is linked to the rest of the global scientific community and appropriate funding agencies" (DST, 2008: 31). Inasmuch as these prerequisites were arguably not all in place, it is unfortunate that the strategy provided no details on how they were to be addressed[17] – thus our rating of 'moderately well addressed'.

3.4 Agency and assignment of responsibility

Q4: Was the TYIP sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it; i.e. is it clear who would take responsibility of specific strategies and be accountable for these strategies?

The table below[18] lists the instances in the TYIP where reference is made either explicitly, or at least indirectly, to the responsible department or agency for a specific intervention. Based on this evidence, we have assigned a rating of 'moderately well addressed' to the TYIP.

[17] On page 1 of the document, the absence of any discussion on these "critical elements" is explained by pointing out that they are all "discussed elsewhere", reference being made (by way of example) to the 1996 White Paper and the NRDS. Of course, neither of these latter documents outlined specific strategic action plans on how shortcomings in these "elements" were to be rectified.

[18] Direct quotations are italicised.

Table 5: Instances of agency identified in the TYIP

Strategy or intervention	Agency specified
Farmer to Pharma	No agency specified.
Space Science and Technology	*(p13) government has proposed a National Space Agency for South Africa to address three strategic objectives:* • *Environment and resource management* • *Safety and security* • *Innovation and economic growth* *(p14) Communication* *This competency area will focus on the development of technologies and applications in collaboration with the end users – mainly the Department of Communications.*
Energy Security	Under 'Major R&D thrusts': • *Clean coal technologies: From an R&D perspective, it makes sense to position SANERI, Eskom, Sasol and various CEF subsidiaries to work together to advance clean coal technologies. (p17)* • Nuclear energy revisited: Reference made to the role/contribution of the Pebble Bed Modular Reactor (p17) • *The promise of hydrogen: The DST is working to establish a specific policy framework to realise opportunities in these areas, along with a science and knowledge base that will ensure that South Africa benefits optimally from the nascent hydrogen economy. (p19)*
Global Change	Only reference to any agency is one of the 'outcomes' by 2018: *An internationally recognised science centre of excellence with climate change research and modelling capability … (p20)*
Human and Social Dynamics	*The DST is working on developing instruments to harvest technology from publicly funded research activity and put it to use on a not-for-profit basis to improve the lives of the poor. (p21)*
Human capital development	No agency specified.
Under 'Knowledge generation and exploitation'	The SET institutions mandated to develop these sectors have a tremendous responsibility over the next 10 years to expand research activities, and to train greater numbers of researchers and engineers. (p28)
Under 'Science and technology across government'	• *The Ten-Year Innovation Plan requires policy leadership by DST and strengthened cooperation across government. The DST is responsible for advising Cabinet on the overall health of science and technology in government, and monitoring research expenditure and innovation in industry. To effect this task, DST conducts an annual review, and presents a national expenditure plan to Cabinet. (p29)* • *DST and its partners, the Human Sciences Research Council and Statistics SA, also publish the annual national R&D survey and the biannual innovation surveys. New mechanisms to monitor important indicators such as patents, technology-trade mix, sector performance and technology balance of payments need to be introduced. To encourage innovation, the DST will partner with provincial governments and facilitate the development of regional innovation systems plans. (p29)*

3.5 Resources for optimal impact

Q5: Was the TYIP sufficiently clear about the resources (especially funding) that would be required to implement its various interventions to optimise success?

References to financing in the TYIP are made with regard to only two domains, as highlighted in Table 6 below. We have thus assessed this aspect as 'moderately well addressed'.

Table 6: Instances of budgets and estimated funding for interventions identified in the TYIP

Strategy or intervention	Budget and/or estimated funding specified
Farmer to Pharma grand challenge	*The government has invested more than R450 million in biotechnology over the past three years, and a number of innovation centres and other facilities have strengthened the R&D base. There is, however, concern that given the breadth of opportunities, current efforts and expenditure are thinly spread. (p10)* *Support for start-up firms needs to be improved. Initial funding is typically obtained through a state agency because start-ups generally have higher R&D costs. But the lack of second- and third-round funding forces many start-ups to take a short-term view. (p10)* *Two of the critical factors cited for growing the biotechnology industry (p11):* • *Improved funding mechanisms to close the gap between basic research and commercialisation; and shorter turnaround times between application and receipt of funding* • *Investment in platforms (including infrastructure) to bridge the gap between research and commercial implementation* *Dynamic research platforms have been initiated and the NSI will require more targeted R&D spending and an enabling regulatory environment to achieve success. (p12)*
From innovation to commercialisation	*The major obstacle to commercialisation of technological innovations is financing, due to the high risk and complexity of R&D investments. New creative funding mechanisms that could help address this problem are emerging in some public-private partnerships. Such partnerships have potential to help close the financing gap and to become effective financing vehicles for medium-high tech and high-tech innovations. (p22)* To address the fragmentation of funding instruments, this Ten-Year Innovation Plan introduces the establishment of a Technology Innovation Agency (TIA). This agency will incorporate, among others, the Innovation Fund and the Biotechnology Regional Innovation Centres. The TIA will help to establish of a network of competence centres focused on market opportunities in partnership with industry and public research institutions. (p22)

3.6 Monitoring and evaluation

Q6: Did the TYIP specify how its progress and ultimate achievements and impact would be monitored and evaluated (including indicators, targets and evidence of achievement)

The TYIP is more committal in respect of stating quantitative benchmarks or targets, and stipulates a range of indicators and metrics that span the output-outcome-impact spectrum (using the programme management framework of the DPME and Treasury) for both the generic, cross-cutting imperatives (those also included in the NRDS) and the new grand challenges.

There are two tables that list cross-cutting high-level indicators:

Indicators	Measure	2018
SA positioned as knowledge-based economy	Economic growth attributable to technnical progress (10% in 2002) National income derived from knowldege-based indutries Proportion of workforce employed in knowledge-based jobs Proportion of firms using technology to innovate GERD/GDP (0.92 in 2005); short-term 2008 target was 1%) Global share in research outputs (0.5% in 2002) High- and medium-tech exports/services as a percentage of all exports/services (30% in 2002) Number of South African-originated US patents (100 in 2002)	30% >50% >50% >50% 2% 1% 55% 250
Research and technology enablers	Matriculants wwith university exemption in maths and science (5.2% maths and 5.9% science in 2005) SET graduates as percentage of all students in public higher education institutions (28% in 2005) Number of SET PhD graduates per year (561 in 2005) Number of full-time equivalend researchers (was 11 439 in 2005) FTE researcher per 1 000 workforce employed (1.5 in 2005)	10% 35% 3 000 20 000 2.6
Human capital development actions and outcomes	*By 2018 South Africa anticipated that it will have* • *210 research chairs at universities and research institutions acress the country by 2010 and 500 by 2018 (58 were in place 2006)* • *About 6 000 PhDs produced per year in all SET disciplines by 2018* • *About 3 000 SET PhDs/doctorates produced by 2018* • *An optimal ratio of technicians commensurate with the country's requirements* • *A 1.5 percent global share of research publications (2006: 0.5 percent)* • *2 100 Patient Cooperation Trety International applications originating in South Africa (2004: 418)* • *About 24 000 patent applications at the South Africant Patent Office (2002: 4 721)*	

In addition, the discussion of each grand challenge is accompanied by a set of targets or indicators. The example of the Farmer to Pharma (bio-economy) grand challenge is given below.

Grand challenge outcomes	*By 2018 South Africa anticipates that it will:* • *Be one of the top three emerging economies in the global pharmaceutical industry, based on and expansive innovation system using the national indigenious knowledge and rich biodiversity* • *Have designed and created the appropriate technolgy platforms, and R&D and innovation infrastructure (including structural biology, functinal genomics, etc.) that facilitate diagnostic and medical solutions* • *Have created and funded five theme-specific consortium-based centres of competences that focus on the five top national health priorities, linked to the growth of the local pharmaceutical industry* • *Increase foreign investment in South African heatlh-related R&D (excluding clinical trials) through reinvigorated health research, with particular emphasis on pharmaceutical R&D* • *Have designed and created a platform in 3rd generation biotechnology for application to plant/animal improvement and biofarming* • *Invest in animal vaccine development and manufacturing facilities to strengthen animal health and production* • *Have created an active biosafety providing regulatory guidance and support for product development in 3rd generation plant and animal biotechnology*

Despite much greater attention to the demands of monitoring and evaluation, many of the outcome statement descriptions in the TYIP are not sufficiently well-formulated, and indicator descriptions are imprecise or even, in some cases, inappropriate. The same applies to the setting of targets where no baseline or time-series data are presented to justify why specific targets have been set. We thus rated the TYIP on this criterion as 'moderately well addressed'.

3.7 Concluding observations about the TYIP

As far as the TYIP is concerned, our assessment shows that the Plan is weak as far as a theory of change is concerned. In addition, the core narrative of the TYIP is built around the imperatives of achieving a knowledge economy but no attempt is made to show how the TYIP builds on the NRDS and gives expression to core challenges identified there. The focus on the five grand challenges as the means whereby South Africa would address its socio-economic problems is deemed to be positive feature of the TYIP. However – as we will argue in Volume 3 (Chapter 5), the 'construction' and 'presentation' of the five grand challenges are uneven and do not conform to the standard logic of what grand challenges are. Finally, we concluded that the M&E elements of the TYIP – especially as linked to each of the grand challenges – were lacking.

Table 7: TYIP formative assessment scorecard

Clarificatory or design evaluation questions	
1. Was the TYIP designed on the basis of a proper problem or needs analysis?	
2. Were the goals and objectives of the TYIP clear and unambiguously formulated?	
3. Did the TYIP take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the plan were aware of potential risk factors that may impact negatively on the achievement of strategic objectives?	
Evaluability assessment	
4. Was the TYIP sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it; i.e. is it clear who would take responsibility for specific strategies and be accountable for these strategies?	
5. Was the TYIP sufficiently clear about the resources (especially funding) that would be required to implement its various interventions to optimise success?	
6. Did the TYIP specify how its progress and ultimate achievements and impact would be monitored and evaluated (including indicators, targets and evidence of achievement)?	

CHAPTER 4

INDICATOR-BASED ASSESSMENT OF THE NRDS AND TYIP

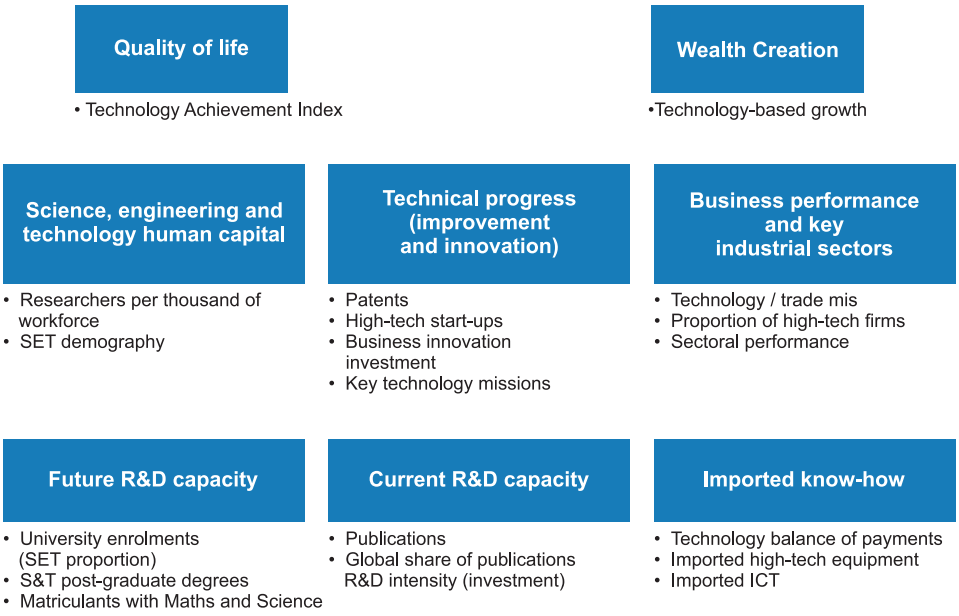
4.1 The NRDS and TYIP indicators

The NRDS and TYIP both contain references to indicators (and sometimes also targets) that presumably need to be monitored in order to assess the progress and ultimate impact of these two strategic frameworks. These indicators are not always well-formulated and some of the targets linked to these indicators are clearly not evidence-based. Nevertheless, we compiled a list of the indicators mentioned in these two documents (excluding duplicate indicators).

Although there is not always a clear alignment between the indicators and the theories of change embedded in the NRDS and TYIP respectively, their inclusion in the respective documents give an indication of how the authors of the documents thought about the operational definition of at least some of the explicit outcomes and possible impacts in these theories of change.

There has been some uptake of the NRDS indicators in the more recent NACI Indicator publications, which also suggest that tracking these indicators has judged to be of some value in monitoring and assessing the performance of the system – or at least of the efficacy of the NRDS.

The diagram below presents the NRDS depiction of linking the key outcomes in the theory of change to "key indicators".



A few comments are in order about this diagram. There is wide-spread confusion in the diagram between 'constructs' or 'dimensions' of the system to be assessed, and either indicator categories or even indicators. Terms such as "technology-based growth" and "SET capital" are best understood as constructs (abstract concepts) that refer to complex phenomena that are not directly measurable. Constructs need to be clearly defined, and operational measures or indicators need to be linked to such constructs in order that they can be measured. Other terms, such as "patents", "university enrolments" and "publications" at best refer to 'indicator categories' but themselves are not properly defined as indicators. The only terms in the diagram that are (approximate) indicators are:

- Researchers per thousand of the workforce (although it is common to distinguish between headcount and full-time equivalents), and
- S&T postgraduate degrees (but again the terms "S&T" and "postgraduate" require further definition).

In mitigation one may argue that it is not the aim of a high-level strategy of this kind to necessarily be specific about each indicator that will be used in monitoring its implementation and impact. However, the terminology should be clearer and it is evident that this is an early indication in the document that the authors of the NRDS did not devote sufficient attention to how the strategy would be monitored and evaluated.

4.2 Monitoring the performance of the NRDS and TYIP: The NACI Indicator reports

One has to look to the NACI Indicator reports to find a more detailed specification of the dimensions of the NRDS theory of change. In the 2015 NACI report, it is unambiguously stated that "NACI has adopted the logical indicator framework suggested within the [NRDS] to monitor the health of the South African NSI. The performance of South Africa's NSI is also benchmarked against the BRIC group of countries (Brazil, Russia, India and China), Japan, South Korea, the United Kingdom and the United States" (NACI, 2015: xii).

The NACI report contains a much longer list of indicators than what had appeared in the NRDS and TYIP. In addition, further operationalisation of key constructs has been done. Table 8 below provides a list of all the dimensions, indicator categories and indicators included in the 2015 NACI Indicator report.

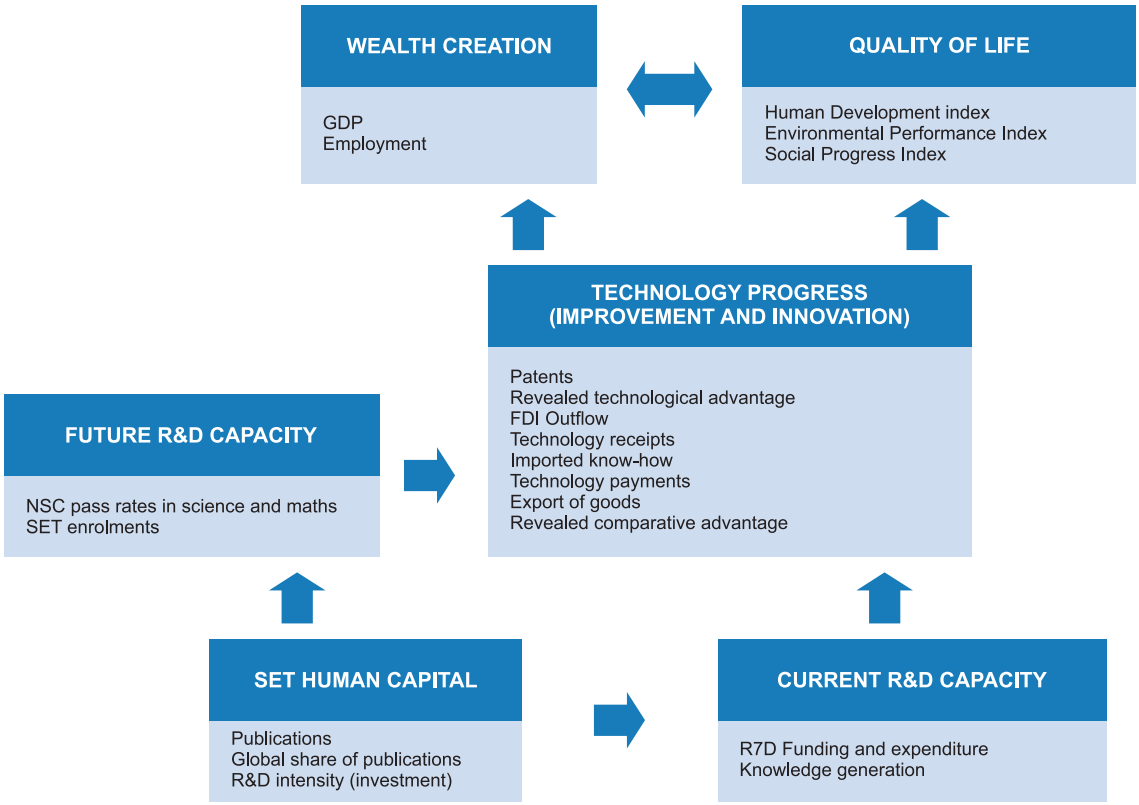
Table 8: Dimensions, indicator categories and indicators in the 2015 NACI Indicator report

Dimension	Indicators
Future R&D capacity	National Senior Certificate (NSC) pass rates in mathematics and physical science SET enrolments
Human capital	SET graduations Doctoral degrees awarded by South African universities SET doctoral degrees awarded by South African universities Number of researchers (headcount)
Current R&D capacity	
R&D funding and expenditure	R&D funding and expenditure by sector Business expenditure on R&D by sector Proportion of R&D expenditure by research field General expenditure on R&D (% of GDP)
Knowledge generation	Total number of publications in WoS World share of publications Citations relative to world (RCR) Number of publications by scientific field International benchmarking of scientific research prioritization (RAI) Higher education research publications (articles) Research collaboration trends (foreign and inter-sectoral)
Technical progress	
Patents	Patents granted to South African inventors at USPTO Share of South African patents in the world total (USPTO) Share of South African patents in foreign origin patents granted by USPTO SA patents by technology class Patents granted to South African assignees
Revealed technological advantage	RTA of various South African technological inventions
Outflow of foreign direct investment (FDI)	FOI outflow (R million) FOI outflow as % of GOP % Global share of FOI outflow Benchmarking of FDI Outflow FDI as % of GDP
Technology receipts	Technology receipts (R million) Technology receipts as % of GDP
Imported know-how	
Technology payments	Technology payments (R million) (Table 5.1) Technology payments as % of GDP (Table 5.1) Benchmarking of technology payments (Table 5.2)
Inward flow of foreign direct investment (FOI)	FOI Inflow (R million) (Table 5.3) FOI Inflow as % of GDP (Table 5.3) % World share of FDI inflow (Table 5.3) Benchmarking of FOI inflow (Table 5.4)
Business performance and key industrial sectors	
Export of goods	Export performance of various South African merchandise by technological intensity Benchmarking of export performance by technology intensiveness
Revealed comparative advantage	Benchmarking of South Africa's RCA

Dimension	Indicators
Wealth creation	
GDP	Regional distribution of economic activity Benchmarking of contributions of different sectors to the economy
Employment	Labour force characteristics by province Labour force characteristics by population group Labour force characteristics by gender Benchmarking of South African employment statistics
Quality of life (HDI Index, Environmental Performance Index and Social Progress Index)	

Redrawing the NRDS theory of change at the level of main dimensions and indicator categories produces a different picture (see diagram below). In this version of the diagram, NACI has been tracking more than 60 indicators.

Figure 8: Reconstructed theory of change for the TYIP



In the NACI annual report of 2009, NACI set out to assess progress towards achieving the targets set out by the TYIP. Although done in 2009, NACI used the most recent data (at the time) and made projections and assessments in the shape of a "performance barometer" of the probability that the 2018 targets would be met. However, NACI acknowledged that some of the indicators used in the TYIP were not clearly defined and were therefore not measurable.

4.3 Summary scorecard for the NRDS and TYIP indicators and assessment

In this section, we provide the summative assessment scorecard of the indicators for which targets had been set in either the NRDS or TYIP, based on the framework adopted by NACI and using data up to most recent available year. In the final section (4.4), we provide the data and assessments for each individual indicator. The summary scorecard in Table 9 below employs the following colour-coded assessment legend:

- Target achieved
- Target partially achieved
- Target not achieved
- Poor formulation/conceptualisation of indicator, indicator not measurable with

Table 9: Summary scorecard for the NRDS and TYIP indicators and assessment

Indicator number and name		Target rating	Trend
1a	Percentage of Matriculants with Mathematics passes (>60%)		
1b	Percentage of Matriculants with Physical Sciences passes (>60%)		
2	Total SET University enrolments		
3	SET students as a percentage of age cohort		
4	SET graduates as percentage of all students in public higher education institution		
5	Number of SET PhD graduates per year		
6	Number of FTE researchers		
7	FTE researchers per 1 000 employed		
8	Number of SET practitioners per 10 000 of the workforce		
9	Number of research chairs at universities and research institutions		
10	World share of research outputs		
11	GERD/GDP		
12	Government R&D expenditure/GDP		
13	Civil GERD as a proportion of GDP		
14	Number of SA originated US patents		
15a	Patent applications at the South African Patent Office		
15b	Number of Patent Cooperation Treaty International applications originating from South Africa		
16	High- and medium-tech exports/services as a percentage of all exports/services		
17	Economic growth attributable to technical progress		
18	National income derived from Knowledge-based industries		
19	Proportion of workforce employed in knowledge-based jobs		
20	Proportion of firms using technology to innovate		
21	Intellectual property net cost to SA (copyright and royalties)		
22	Internet hosts per 1 000 people		
23	Telephone density per 1 000 people		

The results of the scorecard show that the majority of the expected outcomes and impacts of the NRDS and TYIP have not been achieved. In our assessment, only 16 of the stated 23 were sufficiently well-defined or relevant to allow for an assessment against the available evidence. Our assessment of the remaining 16 indicators shows that in the majority of cases (13) the stated targets were not met. On the basis of this one may be tempted to conclude that the NRDS and TYIP have failed. However, such a general conclusion is not warranted. There are at least three reasons why one should be cautious in drawing a general and absolute conclusion about the success or failure – especially of high-level strategies.

Firstly, we would argue that the indicators in the NRDS and TYIP are best understood as referring to expected changes in the **STI system** and not as indicators that are linked to the strategic objectives and outcomes of the **NRDS and TYIP,** respectively. We have already discussed at length that neither the NRDS nor the TYIP devoted sufficient attention to constructing a rigorous theory of change with well-formulated objectives, outcome statements, and outcome and impact indicators. Because of this design weakness, *it is simply not appropriate to use the indicators in these two documents as appropriate measures of success or failure of the two strategic frameworks.*

Secondly, in addition to the misalignment between the indicators and the goals and objectives as stated in the two documents, we have also highlighted the fact that the *targets* that have been set for many of the indicators had not been based on adequate empirical investigation or prior analysis. Many of the targets are not evidence-based and in some cases are simply far-fetched. As a result, the underlying data that have been used to populate these indicators (as in the NACI Indicator reports) are often irrelevant and inappropriate as 'tests' of the NRDS and TYIP theories of change. Poor target-setting and inappropriate evidence provide further reason as to why it is not fair to draw conclusions about the success or failure of these two strategic frameworks in terms of the current indicator set.

Thirdly, and importantly, we believe that the ultimate success or failure of the NRDS and TYIP is best assessed in terms of the success or failures of the specific subsidiary strategies referenced in these documents. In this sense one interprets the NRDS and TYIP more as *strategic frameworks* that contain in themselves a list of more concrete and achievable interventions and programmes. In the analytical framework for this study, we have labelled this as our Level 2 analysis of the individual strategies and interventions. In the final analysis, the 'success' or 'failure' of the NRDS and TYIP must be based on whether the specific strategies and interventions that they had identified have subsequently been properly designed and implemented, and whether these strategies and interventions have produced positive achievements and impact.

4.4 Assessment of individual indicators

Indicator 1: Matriculants with university exemptions in Maths and Science

The target is stated as 10% in 2018, as per below. Recent data is available for the proportion of Matriculants who have passed Mathematics and Physical sciences with a pass mark of more than 60%. It is unclear, from both the NRDS and the TYIP, what the benchmark for 'exemption' is. Although there is an upward trend in the case of the Physical sciences, the fact that there has been a decline in the proportion of Mathematics passes and that the overall target has not been reached resulted in a **RED** score (i.e. target not achieved).

Source	Indicator	2002	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
NRDS	Matriculants with university exemptions in Maths and Science*	3.4	-				(7.5)						
TYIP	Matriculants with university exemption in Maths**	-	5.2				-						(10)
	Matriculants with university exemption in Science**	-	5.9				-						(10)
Percentage of Mathematics passes (>60%)^		-	-	9.4	8.4	7.1	8.0	10.8	7.6	7.0	7.6	8.0	7.0
Percentage of Physical Sciences passes (>60%)^		-	-	3.0	6.2	6.3	6.8	7.6	5.5	5.4	6.4	7.3	7.6

*Source: NRDS (DST, 2002: 32); **Source: TYIP (DST, 2008: 8); ^Source: South African Science Technology and Innovation Indicators Report (2019: 30)

Indicator 2: Proportion of SET tertiary students (% of all tertiary students)

The formulation of this indicator in the NRDS is unclear. A clearer formulation would be 'Total SET university enrolments as a percentage of total enrolments'. The target in the NRDS for 2012 was set at 30%. In 2012, less than 29% of all students enrolled at South African HEIs were in SET fields and the target of 30% was only reached in 2016. We therefore assess the indicator as **RED**.

Source	1990	2002	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
NRDS**	20	27	-	-	-	-	-	-	-	(30)	-	-	-	-	-
NACI Report^		-	28.7	28.5	28.2	28.1	28.3	28.1	28.2	28.7	28.8	29.6	29.9	-	-
HEMIS tables*		-	28.7	-	-	-	-	-	-	28.7	-	-	-	30.3	29.9

^Source: Department of Higher Education and Training/NACI Report (2016: 7); *Source: DHET HEMIS tables; **Source: NRDS (DST, 2002: 32)

Indicator 3: SET students as a percentage of total age cohort

The formulation of this indicator is unclear. We assume that this indicator refers to total enrolments in SET fields across all qualifications. However, it is unclear against which age cohort this indicator is measured. Data on age distribution (StatsSA) includes categories 15-19 years, 20-24 years, 25-29 years and 30-34 years. We can therefore not assess progress made towards this target (**BLUE**).

Source	Indicator	1990	2002	2012
NRDS*	SET students (% of total age cohort)	20%	27%	(30%)

*Source: NRDS (DST, 2002: 32)

Indicator 4: SET graduates as percentage of all students in public HEIs

The formulation of this indicator is unclear. A clearer formulation would be 'Total SET graduates as a percentage of all tertiary graduates across qualifications'. The target set out in the TYIP for 2018 is 35% with a baseline of 28%. The latest data (2017) show the proportion of SET graduates at just more than 29%, which is less than the target and we therefore assess this indicator as **RED**.

Source	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
TYIP*	28											(35)
NACI Report^		29.4	28.5	27.9	28.7	29.4	29.4	30.0	30.0	29.1	29.2	-
HEMIS tables**	27.8	29.1								29.1	29.2	-

Source: Department of Higher Education and Training/NACI Report (2017: 21); *Source: TYIP (DST, 2008: 8); **Source: DHET HEMIS tables; ^NACI report (2019: 26)

Indicator 5: Number of SET PhD graduates per year

In the TYIP, a target of 3 000 SET PhD graduates per year was set for 2018 which implied an expected five-fold increase over 13 years. At the same time, the TYIP anticipated that by 2018, 6 000 doctorates would be produced in SET fields. In 2018, South Africa produced slightly more than 3 000 PhD graduates in total. The TYIP target does not take into account the conditionalities around PhD production, which includes institutional enrolment planning for SET fields. In order to set field specific targets, there needs to be evidence that such targets are achievable, and this target is a clear example of non-evidence based target setting. Recent data on the number of doctoral graduates in SET fields shows less than 1 700 PhD graduates in 2018, which is much lower than the target of 3 000. We therefore assess progress towards this target as **RED**.

Source	Indicator	2005	2014	2015	2016	2017	2018
TYIP*	Number of SET PhD graduates per year	561					(3 000)
HEMIS**			1 130	1 263	1 384	1 589	1 669

*Source: TYIP (DST, 2008: 8); **Source: HEMIS tables

Indicator 6: Number of FTE researchers

In the TYIP a target of 20 000 FTE researchers was set, with a base value of 11 439 in 2005. No indication is given for the source data for the 2005 value, and it does not correspond with what is reported in the South African National R&D Survey Statistical Report. It closely reflects the number of FTE researchers excluding doctoral students and post-doctoral fellows. However, this is not a statistic directly reported for total number of FTE researchers in the survey; it is only reported for the higher education sector.

Source	2005	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
TYIP*	11 439											(20 000)
R&D survey**	17 303	19 384	19 793	18 719	20 115	21 382	23 346	23 571	26 159	27 656	29 515	

*Source: TYIP (DST, 2008: 8); **Source: South African National Survey of Research and Experimental Development Statistical Report 2013/14 and 2017/18

The inclusion or exclusion of doctoral students and post-doctoral fellows has a significant effect on this indicator; this is the case for total headcount researchers, which is reported in the South African National R&D Survey Statistical Report.

Indicator	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Including doctoral students and post-doctoral fellows	39 955	40 797	37 901	40 653	42 828	45 935	48 479	51 877	56 761	61 840
Excluding doctoral students and post-doctoral fellows	28 952	29 255	25 300	25 954	27 314	28 014	28 723	29 455	33 035	36 233

Source: South African National Survey of Research and Experimental Development Statistical Report 2017/18

If the indicator refers to the number of FTE researchers with postdoctoral and doctoral students included, then the target has been achieved and the assessment is **GREEN**.

Indicator 7: FTE researchers per 1 000 workforce employed

The TYIP presents "FTE researchers per 1 000 workforce employed" as a measure of "research and technology enablers", with a value of 1.5 for 2005 and a target of 2.6 for 2018. The South African National Research and Development Survey reports on **researchers (FTE) per thousand employed**.[19] The R&D survey reports do not produce long-term time series data for this indicator; however, the most recent three years are presented in each South African R&D Survey Statistical Report. While the most recent data is for 2017, it is far from the 2018 target. We therefore assess the progress on this indicator as **RED**.

Source	Indicator	2005	2013	2014	2015	2016	2017	2018
TYIP*	FTE researchers per 1 000 work force employed*	1.5						(2.6)
R&D Survey^	Total researchers (FTE) per 1 000 in total employment^		1.6	1.5	1.7	1.7	1.8	

*Source: TYIP (DST, 2008: 8); ^Source: South African National R&D Survey 2017/18 and 2015/16 Statistical Reports

[19] The South African National Survey of Research and Experimental Development defines total employment per Stats SA Labour Force Survey definition; i.e. persons aged 15-64 who, during the reference week, did any work for at least one hour, or had a job or business but were not at work.

Indicator 8: Number of SET practitioners per 10 000 of the workforce

No indication in the NRDS is given for the source of the 2002 data, nor could any data source for this indicator be located. No assessment towards progress of this indicator could thus be made (**BLUE**).

Source	Indicator	1990	2002	2012
NRDS*	Number of SET practitioners per 10 000 of workforce	Not available	7	(11)

*Source: NRDS (DST, 2002: 32)

Indicator 9: Number of research chairs at universities and research institutions

The TYIP set a target of 500 research chairs to be established in 2018. However, in 2018 (June), there were 198 operational research chairs. We therefore assess progress towards this target as **RED**.

Source	Indicator	2006	2010	2018
TYIP	Number of research chairs	58	(210)	(500)
SARChI review*	Number of research chairs			198

*Source: SARChI programme review (Volume 5: Annexure 7 of this report)

Indicator 10: World share of research outputs

The TYIP presents "Global share of research outputs" as one of the measures of the indicator of "South Africa's position as a knowledgebase economy". While the plan does not explicitly state what is considered as research outputs, it states that "the principal qualitative measure of knowledge production is the output of original articles published in scientific journals" (DST, 2008: 26). It provides a baseline of 0.5% for 2002 and a target of 1% for 2018. However, later in the document, one of the anticipated outcomes of the TYIP is a global share of research publications of 1.5%. The source of the 2002 value is not given. An analysis conducted by CREST using the WoS micro-data, and defining research outputs as articles and reviews using full-paper counting, provides the time series data. Measured against the 0.7% target set out in the NRDS, in 2012 the target was met. The most recent data for 2018 show the world share of publications at 0.95%. Although the latest world share falls slightly below the 2018 target of 1%, due to the near doubling of the world share since 2002, our assessment of this indicator is **GREEN**.

Source	Indicator	2002	2010	2011	2012	2013	2014	2015	2016	2017	2018
NRDS^	Global share of research outputs	0.5			(0.7)						
TYIP*	Global share of research output	0.5									(1)
WoS (CREST)**	World share of publications	0.5	0.72	0.77	0.79	0.81	0.86	0.90	0.95	0.96	0.95

*Source: TYIP (DST, 2008: 8); **Source: Web of Science, CREST; ^Source: NRDS (DST, 2002: 32)

Indicator 11: GERD/GDP

The short-term target for GERD/GDP was set for 1% by 2008 and 2% for 2018 in the TYIP. Since 2013/14, GERD/GDP has been calculated using constant 2010 prices. In previous R&D reports, this was calculated using constant 2005 prices, hence the difference in the 2005 value in previous survey reports. The R&D Survey data (and thus OECD data) provide data that retroactively uses the 2010 prices. The latest data (2017/18) shows that GERD/GDP was just over 0.8%, which falls short of the 2% target set for 2018. From this, our assessment of this indicator is **RED**.

Source	2005	2008	2012	2013	2014	2015	2016	2017	2018
TYIP*	0.92	(1.0)							(2.0)
R&D survey 2017/18**			0.73	0.72	0.77	0.80	0.82	0.83	-
R&D Survey 2012/13^	0.92	0.92	0.76						
OECD^^	0.86	0.89	0.73	0.72	0.77	0.80	0.82		

*Source: TYIP (DST, 2008: 8); **Source: R&D survey 2017/18 & 2013/14 Statistical reports; ^^Source: R&D survey 2012/13 Statistical report; ^Source: ECD data: https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm (accessed 6/1/2020)

Indicator 12: Government R&D expenditure/GDP

The target for government R&D expenditure/GDP was set at 0.66% by 2012 in the NRDS. No indication is provided in the NRDS for the source of the 1990 or 2002 values. The OECD Frascati manual distinguishes between four sectors, namely: government, higher education, business and not-for-profit sectors. The South African National R&D Survey disaggregates the government sector into government and science councils sectors. It is unclear whether the target of 0.66% was for the government sector only or for the government sector in combination with the science council sector. Regardless, even with the two sectors combined at 0.19% in 2012, the government expenditure on R&D falls short of the 2012 target of 0.66%. By 2017, the most recent data available, the target has still to be reached. From this, our assessment of this indicator is **RED**.

Source	Indicator	1990	2002	2012	2013	2014	2015	2016	2017	2018
NRDS*	Government R&D expenditure/GDP	0.48	0.36	(0.66)						
R&D survey**	Government R&D expenditure/GDP			0.04	0.05	0.05	0.05	0.05	0.05	-
R&D survey**	Government R&D + Science Council expenditure/ GDP			0.16	0.17	0.18	0.19	0.19	0.19	-

*Source: NRDS (DST, 2002: 33); **R&D survey 2017/18 Statistical report

Indicator 13: Civil GERD as a proportion of GDP

The NRDS states a target for "government civilian R&D as a proportion of R&D" at 0.6% but does not clearly define what is meant by the term "government civilian R&D", as no such sector is reported on in the R&D Survey. However, it does report on civil GERD as a proportion of GDP. When measured against the set target of 0.6%, we see that in 2012, civil GERD as a proportion of GDP was slightly below 0.7%. Therefore, our assessment for this indicator is **GREEN**.

Source	Indicator	1990	2002	2012	2017
NRDS*	Government civilian R&D as a proportion of GDP	0.36% estimate	0.29%	(0.6%)	
R&D survey**	Civil GERD as a proportion of GDP			0.69	0.79

*Source: NRDS (DST, 2002: 33); **R&D survey 2017/18 & 2013/14 Statistical reports

Indicator 14: Number of South African-originated US patents

The formulation of this indicator is unclear. We assume that this indicator refers to utility patents, originating from South Africa and granted by the US Patent and Trademark Office (USPTO). The NRDS set a target of more than 100 patents granted by 2012. Data from the USPTO shows that in 2012, this target was met as 158 patents originating from South Africa were granted by the USPTO. However, assessing the target of 250 set out by TYIP, the latest data in 2015 indicated fewer than 200 patents granted. Without data for 2018 it is difficult to make an assessment, but given the steady increase in the number of granted patents, we assess progress towards this indicator as a positive trend (**GREEN**).

Source	Indicator	1990	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2018
NRDS	No. of SA originated US patents	100	100										(>100)				
TYIP*																	(250)
USPTO**	No. of Patents Granted as Distributed by Year of Patent Grant		123	131	115	108	127	116	124	139	142	144	158	181	181	199	

*Source: TYIP (DST, 2008: 8); **https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_all.htm

Indicator 15: Number of patent applications

The TYIP anticipated that by 2018, there would be 24 000 patent applications to the South African office. Data from the CIPC show that in 2018 just over 8 500 patent applications had been lodged, which is much lower than the anticipated target of 24 000. We therefore assess progress towards this indicator as **RED**.

Source	Indicator	2002	2012	2013	2014	2015	2016	2017	2018
TYIP	Patent applications at the South African Patent Office	4 721							(24 000)
CIPC*	Total patent applications lodged at CIPC		9 426	8 906	10676	9 325	9 105	8 721	8 571

*CIPC Annual Report 2018/2019 (p26)

The TYIP also anticipated that by 2018 there should be 2 100 Patent Cooperation Treaty International (PCT) applications originating in South Africa. The benchmark in 2004 was 218. Time series data from the WIPO show that there has been a decline in the number of PCT applications for South Africa at the WIPO, and that in 2018 there were only 275 PCT applications. This is much lower than the anticipated target of 2 100. We therefore assess progress towards this target as **RED**.

Source	Indicator	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
TYIP	Number of Patent Cooperation Treaty International applications originating from South Africa	418														(2 100)
WIPO^	Total PCT applications by filing date and country of origin	412	360	424	406	394	375	291	309	313	351	313	313	287	295	275

^WIPO data centre: https://www3.wipo.int/ipstats/searchForm

Indicator 16: High- and medium-tech exports/services as a percentage of all exports/services

Both the NRDS and the TYIP stated targets for high- and medium-tech exports – the former at 40% by 2012 and the latter at 55% for 2018. Neither the NRDS nor the TYIP provided the data source of the baseline value and they differed in their formulation of the indicator. This lack of clarity of indicator and data source makes it difficult to track the progress towards achieving the targets. The 2009 NACI Annual Report presents their assessment by referring to the indicator "medium- and high-technology manufacturing exports as a percentage of all manufacturing exports". If we take a similar approach by looking at "medium and high technology exports as a percentage of all exports" we see that the 2012 target has been met, although the 2018 target is unlikely to be met. Our assessment of this indicator is thus **RED**.

Source	Indicator	2002	2012	2013	2014	2015	2016	2017	2018
NRDS^	High and medium-tech exports	30	(40)						
TYIP*	High- and medium-tech exports/services as a percentage of all exports/ services	30							(55)
World Bank Indicators**	Medium and high-tech exports (% manufactured exports)	44.7	44.7	43.6	46.2	49.8	50.5	46.7	-

^Source: NRDS (DST, 2002: 33); *Source: TYIP (DST, 2008: 8); **Source: World Bank Indicators World Development Indicators

Indicator 17: Economic growth attributable to technical progress

Both the NRDS and the TYIP set targets for "economic growth attributable to technical progress". The 2009 NACI Annual Report states this as one of the indicators which they consider not assessable due to "either a lack of reliable information or lack of clarity in the definition of the indicator" (NACI, 2009: 15). For similar reasons, we are unable to assess this indicator given that the indicator is ill-defined (**BLUE**).

Source	Indicator	2002	2012	2018
NRDS	Economic growth attributable to technical progress	10%	(25-30%)	
TYIP	Economic growth attributable to technical progress	10%		(30%)

Source: TYIP (DST, 2008: 8)

Indicator 18: National income derived from knowledge-based industries

Both the NRDS and the TYIP set targets for "national income derived from knowledge based-jobs". As is the case with indicator 17, the 2009 NACI Annual Report includes this as one of the indicators which they consider not assessable due to "either a lack of reliable information or lack of clarity in the definition of the indicator" (NACI, 2009). For similar reasons, we are unable to assess this indicator given that the indicator is ill-defined (**BLUE**).

Source	Indicator	2018
TYIP*	National income derived from knowledge-based industries	(>50%)

*Source: TYIP (DST, 2008: 8)

Indicator 19: Proportion of workforce employed in knowledge-based jobs

The TYIP set a target to increase the "proportion of workforce employed in knowledge-based jobs" to **more than 50%** in 2018. However, no benchmark for this indicator is set. The indicator is also poorly formulated as "knowledge-based jobs" are not defined. NACI, in its 2009 Annual Report, used the Labour Force Survey to establish the percentage of professional and technical workers. In 2018 (quarter 4) the percentage of professional workers and technicians constituted 14% of occupational workers. This is far below the projected target of 50% and we therefore assess this target as **RED**.

Source	Indicator	2018
TYIP*	Proportion of workforce employed in knowledge-based jobs[20]	(>50%)
Labour force survey**	Proportion of professional workers and technicians of all employment (by occupation)	14%

*Source: TYIP (DST, 2008: 8); ** StatsSA Quarterly Labour Force Survey 4th Quarter (2018: 4)

Indicator 20: Proportion of firms using technology to innovate

A potential source of data for this indicator is not indicated in the TYIP. The NACI report mentions the Accenture Innovation Index, and other sources mention the Bloomberg innovation index, but these indices use a number of indicators to calculate a composite score or ranking. CeSTII' s South African Innovation Survey (2008) reports the percentage of innovative enterprises that use technological innovations, but not as a percentage of all firms. An assessment based on this indicator is thus not possible (**BLUE**).

Source	Indicator	2018
TYIP*	Proportion of firms using technology to innovate	(>50%)

*Source: TYIP (DST, 2008: 8)

[20] The Global Innovation Index has a composite indicator which measures business sophistication through, among others, knowledge workers, and knowledge-intensive employment (%). However, the Index does not provide data, only a score and a rank. CeSTII's South African Innovation Survey (2008) reported on the number of employees employed in enterprises with innovation activities.

Indicator 21: Intellectual property net cost to South Africa (copyright and royalties)

With regard to intellectual property net cost to South Africa, the NRDS simply sets a target to "improve the ratio". We therefore assume that this refers to the ratio between expenditure and revenue associated with IP in South Africa. As no benchmark or target for this ratio is set, we cannot assess progress made towards this measurement. We include, however, data from the World Development Indicators. When looking at the ratio of IP payments against that of IP receipts we see that the ratio has improved towards 2012. We therefore assess this indicator as a positive trend (GREEN).

Source	Indicator	1990	2002	2012
NRDS	Intellectual property net cost to SA (copyright and royalties)	R200 million	R800 million	(Improve ratio)
World Development Indicators	Charges for the use of intellectual property, payments (BoP, current US$)	-	446 513 324	2 017 094 892
World Development Indicators	Charges for the use of intellectual property, receipts (BoP, current US$)	-	19 454 588	124 888 029
	Ratio of payments to receipts	-	23:1	16:1

*Source: NRDS (DST, 2002: 33). 2012 value is a target; **CIPC annual report 2018/19

Indicator 22: Internet hosts per 1 000 people

The OECD publication *Measuring the Information Economy* defines Internet hosts as "any computer system connected to the Internet (via full-time or part-time, direct or dial-up connections), although some systems may not be accessible owing to technologies such as firewalls. Hosts can thus be thought of as an indicator of the minimum size of the public Internet" (OECD, 2002: 40). This appears to be an outdated indicator as the latest data available for this indicator for any of the OECD countries is for 2001. This indicator also used to be included in the Human Development Index until 2002, after which it was replaced by "number of internet users per 100/internet users as a percentage of total population". The difference between the reports is likely due to the practise of reporting data for the most recent year available. An assessment based on this indicator is thus not possible (BLUE).

Source	Indicator	1990	1995	2000	2002	2012
NRDS*	Internet hosts per 1 000 people	0			8.4	(64)
HDI 2001**	Internet hosts per 1 000 people		1.2	8.4		
HDI 2002^	Internet hosts per 1 000 people	1.2		4.4		

*Source: NRDS (DST, 2002: 33). 2012 value is a target; **Source: Human Development Index 2001 (p61); ^Human Development Index 2002 (p188)

Indicator 23: Telephone density per 1 000 people

The data source for the NRDS is not given. The 1990 data point corresponds with the number reported in the 2001 Human Development Index Report for telephone mainlines per 1 000 people, but not with the 2002 value reported in the Human Development Report of 2004. This indicator is one of the Millennium Development Goal indicators. After 2015, this Millennium Development Goal indicator was updated to "active fixed telephone lines per 100 people", for which the data is available as part of the World Bank's World Development Indicators. Due to the change in the indicator and the lack of recent data or data for 2012, an assessment based on this indicator is not possible (BLUE).

Source	Indicator	1990	2002	2012	2013	2014	2015	2016	2017	2018
NRDS*	Telephone density per 1 000 people	87	270	(700)						
World Bank**	Fixed telephone subscriptions (per 100 people)	9.0	10.7	9.2	7.2	6.7	7.5	8.0	8.4	5.4
HDI^	Telephone mainlines per 1 000 people	87	107							

*Source: NRDS (DST, 2002: 33). 2012 value is a target; **Source: World Bank World Development Indicators; ^^Human Development Reports (2001, 2004)

Volume 3

SUBSIDIARY STRATEGIES AND INTERVENTIONS: MAIN FINDINGS

Volume 3 is devoted to a discussion of our findings and recommendations based on the reviews of the 21 subsidiary strategies and interventions as identified and 'extracted' from the NRDS and TYIP. Our discussion and main conclusions here complement our discussion in Volume 2 where we focused on the NRDS and TYIP documents.

Navigation

The discussion is organised thematically in six chapters:

1. System governance, legislation, and monitoring, evaluation and learning (MEL)
2. Human resources for science and technology
3. Science and indigenous knowledge systems
4. Technology strategies and missions
5. The grand challenges
6. Financing

In each of these chapters we have summarised and integrated the findings of the individual reviews as produced by the team members, with a specific focus on the context and strategic goals and/or objectives of each strategy/intervention; a timeline of key developments relating to each domain including references in the 1996 White Paper, the NRDS, the TYIP and the 2019 White Paper; our assessment of the strategy and/or implementation plan design; and the assessment of the progress and/or achievements of the strategy/intervention. It is important to emphasise that our abbreviated discussion in this volume inevitably loses much of the detail and nuance that is present in the individual reviews. In some cases, the text has also been shortened and even reorganised for the purposes of this section of the report. This may have come at the expense of understanding some of the text without the more comprehensive contextualisation that is found in the individual reviews. The reader is therefore encouraged to refer to the full reviews in Volume 5.

SYSTEM GOVERNANCE, LEGISLATION AND MEL

1.1 Introduction

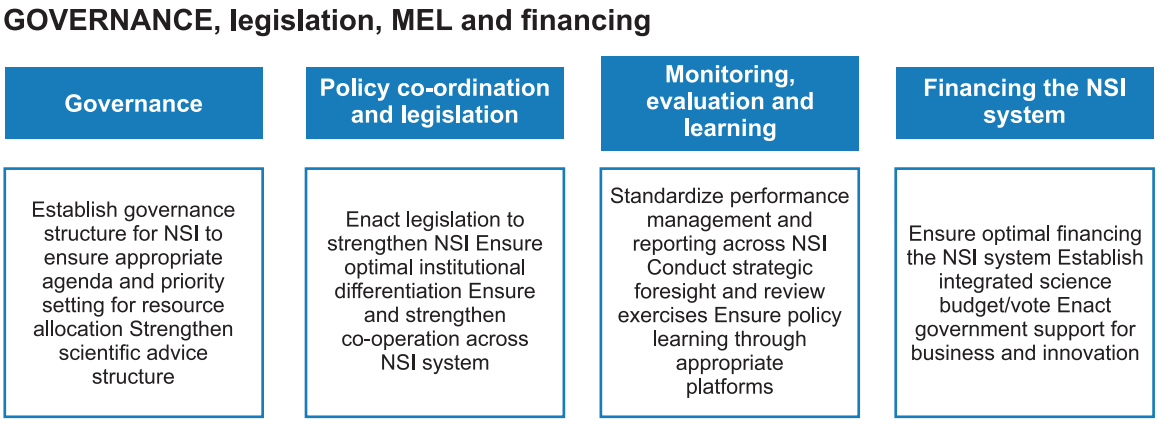
Governments have a number of clearly defined roles and responsibilities to ensure that science, technology and innovation in a country are addressed in an effective and efficient manner. Policy debates over many decades have raised questions about how this 'mandate' should be exercised. STI systems do not exist in isolation: they are embedded in and influenced by other social systems in a country as well as international developments. The size and shape of the NSI differs from country to country which leads to differences in the way that governments address the main challenges of the NSI.

Nevertheless, there is consensus in the literature that governments must assume responsibility for at least the following functions:

- Establish appropriate governance structures and systems to ensure appropriate and effective priority-setting and resource allocation for the STI activities in a country;
- Creating an optimal policy, legislative and regulatory framework to optimise scientific and innovation performance;
- Ensure the growth of the STI system as well as clear differentiation and articulation of institutional missions and mandates;
- Establish and maintain appropriate modes of monitoring and evaluation of the performance of the NSI to ensure accountability, value for money and policy learning; and
- Ensure optimal financing of the STI system – both for public R&D as well as to ensure private investment in R&D.

The figure below presents a summary of these government functions.

Government functions with regard to STI governance, legislation, MEL and financing



This chapter addresses the first three functions: Section 1.2 is devoted to a discussion on system governance and coordination (see Volume 5: Annexure 1); section 1.3 discusses intellectual property legislation (see Volume 5: Annexure 2); and section 1.4 focuses on system-level monitoring, evaluation and learning. The fourth function (financing) is discussed in Chapter 6.

1.2 System governance and coordination

1.2.1 Context and overview

The NRDS and TYIP refer extensively to the need to strengthen and improve governance of the national STI system, especially in respect of the system of public sector science institutions. They also list a range of specific imperatives and proposed or intended initiatives. Nonetheless, in neither instance did these commitments result in identifying a systematic and comprehensively codified strategy for pursuit of all the stated imperatives.

However, in March 2004, the Department submitted to Cabinet a memorandum (Cabinet Memorandum No. 9) outlining a new Strategic Management Model (SMM), which sought to clarify and institutionalise certain aspects of the respective roles of the DST and other government departments in respect of science and technology in the public sector. The SMM was conceptualised as a platform to take forward some of the system-level governance imperatives of the NRDS, basically by clarifying the respective roles of the DST and other science-intense departments. Cabinet approved the concept, granting permission to the Department to "investigate the implications of the strategic management model for government's portfolio of science and technology activities and provide a detailed proposal for its consideration" (Cabinet Memorandum No. 19 of 2004).

In October 2004, the Department followed up on the earlier memorandum, submitting to Cabinet a memorandum entitled "Implementation of the new Strategic Management Model for South Africa's science and technology system" (Cabinet Memorandum No. 19). It proposed a number of specific interventions in the STI sector, some of which had their origin in the NRDS to a greater or lesser extent. The provisions of this memorandum, all of which were approved by Cabinet, are analysed in further detail below.

The TYIP later highlighted many of the same imperatives as had the NRDS earlier, signalling that by 2008 the DST was of the view that insufficient progress had been made on those issues because they had not been acted on since the NRDS was published – or because the initiatives taken earlier (in response to Cabinet Memorandum No. 19) had been unsuccessful. No lower-level strategies were formulated by the DST in respect of system-level governance issues raised (again) in the TYIP after it had been published in 2008. However, several of those same system-level governance imperatives and recommendations that were raised in the TYIP (and previously in the NRDS) have found their way into the 2019 White Paper – suggesting that again they are not yet satisfactorily resolved in the eyes of the Department and Minister. The following quote summarises the 2019 White Paper's intentions with regard to bringing about a coherent and inclusive NSI (DST, 2019: xi):

In addition to measures to support partnerships among NSI actors at all levels, interventions aimed at improving the policy coherence and coordination, as well as the governance, of the NSI will be introduced. Among these will be the establishment of a Ministerial STI Structure under the guidance of the Minister of Science and Technology, which will set the STI agenda across government and commit public resources to priority STI programmes. The Ministerial STI Structure will be informed by an annual STI Plenary involving government, business, academia and civil society, to be convened by the Presidency. The National Advisory Council on Innovation (NACI) will be strengthened to advise the Ministerial STI Structure. Policy approaches are introduced to increase coherence in critical areas such as education and skills development, the economy, and social development. Sector coordination will be improved through the adoption of collaborative sector R&D planning, as well as Sector Innovation Funds to concentrate resources on priority sectors. To fully exploit the potential of STI in South Africa, the STI institutional landscape will be expanded in line with the findings of the STI Institutional Landscape Review, and the governance of NSI institutions will be strengthened (including clarifying the mandates of government departments regarding public research organisations, and improving coordination across research institutions and funding agencies). Finally, policy approaches to enhance the M&E capacity of the NSI will be introduced, for instance, conducting regular foresight exercises and developing a new M&E framework for the NSI, with NACI being upgraded so that it can undertake this role.

The Department's struggle to formulate a viable and systematic strategy for achieving – or at least pursuing – policy imperatives to improve system-level governance listed repeatedly in the NRDS, TYIP and 2019 White Paper signals how intractable this challenge is in the world of Realpolitik. The core of this challenge seems to be limited horizontal coherence and integration between agencies in the NSI, and the absence of a Cabinet-level coordinating body that can successfully devise and monitor national-level strategies for innovation, and marshal the resources needed for these.

Two reviews have been published of the STI landscape that assessed, at least in part, the success or otherwise of the implementation of the SMM. The first was the report issued in March 2012 by the Ministerial Review Committee on the Science, Technology and Innovation Landscape. The second was that of the 2017 Ministerial Review Panel on the Science, Technology and Innovation Institutional Landscape which was released in April 2017. Apart from Cabinet Memorandum No. 19 (Implications of the SMM), no derivative strategies for system-level governance imperatives were published by the DST. As a consequence, our review (1) focused on the Cabinet Memorandum as the only derivative 'strategy' intended to translate the NRDS imperatives into strategic activities, and (2) drew on the 2012 Ministerial STIL Review and 2017 Ministerial STIIL Review reports as additional input.

Lastly, subsequent to the release of the TYIP, no specific strategic document was formulated by the DST to take forward the system-level governance imperatives outlined in it. However, as already indicated earlier, many if not most of the relevant imperatives highlighted in the TYIP had earlier been aired in the NRDS – and subsequently been taken up in the Cabinet Memorandum. In evaluating progress against the detailed plans of the Memo, we would thus be reviewing progress explicitly against the relevant system-level governance imperatives of the NRDS, and implicitly against those of the TYIP.

1.2.2 Assessments

This section explores the extent to which the strategic imperatives embedded in the NRDS and TYIP were (a) translated into relevant and specific initiatives outlined in Cabinet Memorandum No. 19, or (b) given effect to in some other manner. Our review has shown that only some NRDS policy intents were taken forward through the SMM Cabinet Memorandum, many were not. As mentioned earlier, many if not most of the system-level governance policy intents of the TYIP were repeats of those or very similar ones that had been included in the NRDS, and no explicit derivative strategies were published by the DST subsequent to the TYIP taking forward such policy intents. Nevertheless, this section also analyses the extent to which these policy intents were pursued, whether explicitly in the context of the TYIP, or whether coincidentally.

In our assessments, we utilise the following legend:

Achieved	Not achieved at all
Target partially achieved	Not possible to make a judgement

The NRDS and TYIP identified three priorities under the following headings:

- The need for a clear articulation and differentiation across government departments as far as responsibilities for funding and R&D performance is concerned;
- The placement of sector specific R&D institutions close to their respective line departments; and
- Actions to ensure optimal coherence and coordination of S&T functions across line departments.

Our review concluded that the first of these priorities was not achieved, the second only achieved in some respects, while the third and fourth policy intents were achieved.

Policy imperative	Corresponding strategy		Evidence
There needs to be a clear allocation of responsibilities between different government departments and institutions regarding both funding and performance in the National System of Innovation. (NRDS: 63)	Drafting of coordinated legislation to operationalise the Strategic Management Model, by 1 October 2004.		This ambitious intervention was not given effect. It seems reasonable to surmise that the political balance of forces ultimately mitigated against this step, which would be tantamount to legislating the existence of the DST, and even the 2019 White Paper has refrained from stating this as a policy option.

Policy imperative	
Several areas require urgent attention over the next decade (TYIP: 29): Interdepartmental science and technology initiatives – In 2007 the DST launched the Science and Technology Managers' Forum to promote greater use of science and technology and strategic coherence between departments. For the forum to be effective, policy administration capacity needs to be further developed.	

Comment: The Forum was quickly displaced by structured inter-departmental agreements and ad hoc bilateral interdepartmental meetings whose frequencies and effectiveness vary considerably across departments and over time. Furthermore, in the context of the annual STA survey, departments were convened by DST to specifically look at S&T expenditure across government.

Policy imperative	
It is recommended here that all sector-specific R&D institutions are best placed in close proximity to line departments with the primary responsibility for the relevant sector (NRDS: 66)	

Policy imperative	Corresponding strategy or intervention	
The role of the Department of Science and Technology will be to coordinate a coherent performance management system for all government-owned laboratories and to have direct responsibility for five cross-cutting institutions. Line departments would have the responsibility to set research goals and budgets for institutions reporting to them. Basic research is a key shared function of the Department of Science and Technology and the Department of Education. Line departments will be involved in innovation in collaboration with the Department of Science and Technology.[21, 22] (NRDS: 17)	The Department of Education and DST will establish an institutional mechanism for the coordinated funding of tertiary education postgraduate research by 1 April 2005.	
	The appointment of DST representatives to the boards of the ARC, MRC, Mintek, South African National Biodiversity Institute (SANBI), Necsa, National Energy Research Institute, and the Water Research Commission from 1 April 2005.	

Comment: While no single mechanism has been established with the specific focus mentioned, the two departments have established a formal MoU and there are occasional bilateral meetings at Deputy Director-General, Director-General and Ministerial levels. There has been evidence of effective cooperation on several issues related to research development and support between the two departments, but this mechanism is entirely dependent on the collegiality between DST and DHET officials, there being no regular structural rationale for systematic, system-level cooperation (hence the rating of 'partially achieved').

DST representatives have been appointed to various boards. However, it seems reasonable to question how effective such a mechanism could be taking into account that the DST representative is but one among many directors, and the significant majority of issues dealt with by the boards and councils of these public research institutions have to do with corporate governance rather than ensuring strategic alignment between the respective institutions and the DST (and across the landscape of public research institutions).

Policy imperative	Corresponding strategy	
The Department of Science and Technology will assemble all inputs into a Science and Technology Budget, and through this instrument advise Treasury, the Cabinet and Parliament of the important dynamics in the system. (NRDS: 65)	Cabinet Memorandum No. 19 stipulated that the DST would undertake a "revision of the 'Science Vote' process for the 2006/07 budgeting process and thereafter."	

Although the eventual decision of Cabinet – on the recommendation of the DST – is contrary to the policy imperative stipulated in the NRDS, it was implemented and ultimately led to the disappearance of the Science Vote in April 2005.

Policy imperative	Corresponding strategy or intervention	
The basic risk management assessment for technology, the national foresight capacity and the integration of individual budgets to produce an aggregate national research and development budget will be the responsibility of the Department of Science and Technology. (NRDS: 65)	The closest initiative mentioned in Cabinet Memorandum No. 19 is that the DST would create "a research and technology transfer support service within the DST to assist sector-specific departments, to be launched in the 2005/06 financial year."	

[21] This clear and unambiguous policy statement appears in the Executive Summary of the NRDS, but is not repeated in the relevant section of the document; or at least, the discussion of this framework in later sections of the NRDS does not map very clearly onto this concise formulation.

[22] This strategic separation of functions is alternately described as follows in a later section of the NRDS (DST, 2002: 24): "The integrative Department of Science and Technology will be responsible for a regulatory framework affecting all institutions with research and development as a primary mandate, whereas the line departments will set objectives and budgets for these institutions within this framework. In addition, the major cross-cutting funding agencies for research and development and innovation will reside under the Department of Science and Technology, as will state-owned laboratories and research organisations with mandates cutting across the responsibilities of many line departments."

With regard to enhanced management of STI budgeting by government, the DST has periodically engaged the National Treasury and other departments in attempts to improve coordination in the allocation of budgets to S&T/R&D activities across government, but no consistent and effective model has emerged that gives effect to the principle of DST 'leadership' in this respect. Also, since 2008 the DST has produced annually an expenditure report on government Science and Technology Activities. The 2019 White Paper continues to make provision for enhanced influence of the DST over this process.

1.2.3 Conclusions

Five years after the NRDS was published, and three after the SMM was implemented through Cabinet Memorandum No. 19, the 2007 OECD review of the NSI found that system-level governance of STI could be and needed to be improved. These findings were echoed later by the 2012 Ministerial STIL Review and the 2017 Ministerial STIIL Review, which reached similar conclusions about the effectiveness of the SMM in bringing about the needed changes, which had, in fact, been fairly well articulated in the NRDS and to a lesser extent in the TYIP.

The SMM attempted to create a conceptual basis for differentiating the roles of the DST and other government departments in relation to STI, in order, presumably, to institutionalise these roles in due course through appropriate organisational platforms, interdepartmental agreements, and possibly relevant legislation (as illustrated by one of the actions proposed in Cabinet Memorandum No. 19). Presumably, the choice of activities outlined in the memorandum was assumed at the time to suffice for comprehensive implementation of the SMM as the key intervention to shore up system-level governance and coordination. As discussed above, most of the activities were implemented, and yet the 2007 OECD review as well as the 2012 and 2017 Ministerial reviews all identified ongoing weaknesses. It is therefore difficult to avoid concluding that the SMM constituted an insufficient intervention.

Clearly, the fact that the 2019 White Paper again contains numerous 'policy intents' aimed at improving system-level governance and intergovernmental coordination, indicates that the DST continues to struggle with this matter. In particular, it would seem that the key thing the DST has struggled to come to grips with is how to entrench its (assumed) 'responsibility' as its explicit authority to guide, oversee and/or advise other government departments and their entities in respect of science and research, technology and innovation. Only in documents emanating from the DST (such as Cabinet Memorandums and relevant strategies and policies) is the DST vested with the extensive 'responsibilities' outlined in the NRDS and TYIP. To the best of our knowledge this notion is not explicitly repeated anywhere else. Even had there been explicit political statements along such lines, it is doubtful that these alone would have imbued the DST with the authority needed to effect system-level governance as envisaged in the NRDS and TYIP.

Two key interventions would have positioned the DST at the centre of public sector S&T (and research) activities, though they would not have imbued the DST with central responsibility for innovation: namely the transfer into the DST of all major public research institutions, and the establishment of an Act entrenching the DST's functions across the system as a whole. Both these interventions were explicit policy intents at one point or another in the development of Cabinet Memorandum No. 19 (implementing the SMM), but neither was ultimately taken forward. It seems reasonable to assume that this failure is a manifestation of political dynamics prevailing at the highest levels of government at the time.[23]

In summary, several of the NRDS's less intrusive policy intents – that is, those which undermined less the authority of other line departments over their respective public science institutions – were given effect through the implementation of the SMM as laid out in Cabinet Memorandum No. 19. But the more ambitious policy imperatives which would have secured the DST's role as the formal interlocutor on behalf of most public sector science, technology and research activities and institutions have largely not been implemented over the last decade-and-a-half – despite being mostly codified in the NRDS and Cabinet Memorandum No. 19, and repeated to a lesser extent in the TYIP. This lack of substantive movement in entrenching the leadership role of the DST in respect of public sector STI is presumably why the 2019 White Paper still makes extensive reference to the need for strengthened system-level governance of STI.

[23] Without delving into details, it can be disclosed here that this information was confidentially provided by a senior bureaucrat involved with science and technology during the relevant period.

1.3 Intellectual property

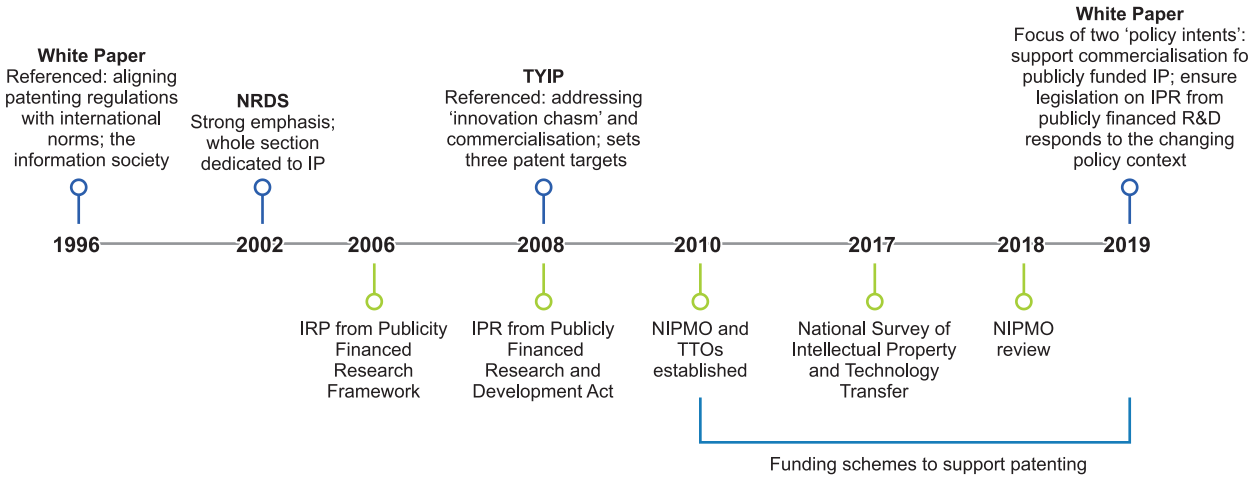
1.3.1 Context, overview and strategic objectives

The review of IP focuses on the statements and objectives relating to IP in the NRDS and TYIP, as well as the *Intellectual Property Rights (IPR) From Publicly Financed Research Framework* (IPR Framework) which was published by the DST in 2006. Taken together, we refer to this as the 'IP strategy'. The review also incorporates the findings of previous reviews.

The rationale relating to IP is stated at various points in the NRDS as the need to follow international precedence in strengthening the regulations pertaining to the management of IP arising from public-funded R&D. The NRDS defined a certain policy approach to IP, particularly that which is developed through public finance, which was then implemented by the DST. The context was considered to be twofold: firstly, the absence of regulation, and secondly, the growing international precedence for such regulation. Importantly, these objectives were developed further in the subsequent IPR Framework (DST, 2006) which was used to guide the development of the legislation and the establishment of NIPMO.

The implementation of IP-related policy and interventions has included the development of the DST IPR Framework (DST, 2006); the promulgation of the Intellectual Property Rights from Publicly Financed Research and Development Act No. 51 of 2008 (IPR Act); the establishment of the National Intellectual Property Management Office (NIPMO); and the establishment of technology transfer offices (TTOs) and funding for activities relating to IP. The timeline of developments is depicted in the figure below, which also highlights the nature and extent of the focus on IP in the 1996 White Paper, NRDS, TYIP and the 2019 White Paper.

Timeline of implementation for the IP strategy

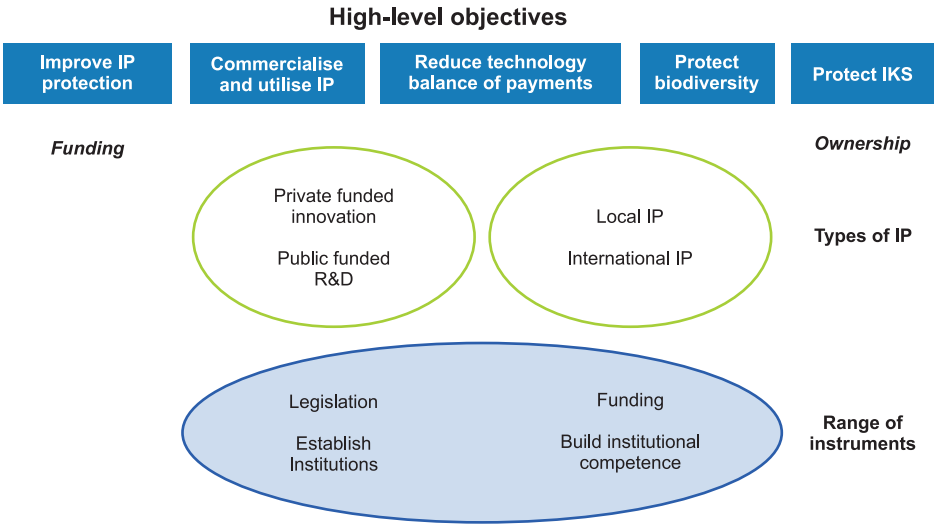


The strategic objectives of the NRDS/TYIP and the IPR Framework can be summarised as shown in the table and figure below, with five broad goals to be achieved through a mixture of four policy instruments, and covering four distinct types of IP, separable by the two dimensions of ownership and source of funding.

High-level objectives relating to IP of the NRDS/TYIP and the IPR Framework

Mission		To meet the urgent need for the creation of a proper framework and enabling legislation for the effective management of IP arising from publicly financed research
Strategic objectives	1	Ensure that we properly protect our IP (develop the national capacity to manage IP, especially IP derived from publicly financed research)
	2	Ensure that we utilise and commercialise our IP (strengthen initiatives for the commercialisation of IP and control South African-owned global IP licenses)
	3	Reduce the net cost (imports minus exports) from the copyright and royalty fees for IP (reduce technology balance of payments)
	4	Ensure that we protect indigenous knowledge and indigenous knowledge systems
	5	Ensure that we conserve South Africa's unique biodiversity

Strategic objectives and instruments of the NRDS/TYIP relating to IP



1.3.2 Assessment

Assessment of the implementation of the IP-related interventions and associated activities for each strategic objective is provided in the table below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation of IP-related intervention activities

Strategy objective	Intervention activities		Evidence
Protect our IP	Strengthen IP legislation and infrastructure covering public-financed R&D: Pass IPR legislation covering public-financed R&D, drawing on the enabling frameworks of global best practice		The IPR Act was introduced in 2008
	Develop South Africa's competencies in IP legislation: Establish competence on best practice in IP legislation		The institutional evaluation of NIPMO has yet to be published but other reviews have been positive on its achievements
	The right of the state to use IP from public-funded R&D in the public interest should be established: Prepare the necessary component in the legislation (walk-in rights)		This was achieved via the legislation
	An acceptable framework for the sale of rights should be established, including the conditions under which the rights can be acquired internationally: Prepare the necessary component in the legislation (sale of rights)		This was achieved via the legislation
	Regulations to be made to recognise inventors, designers and authors who develop IP when financed with public funds to share benefit with their institutions: Gazette the necessary regulations on benefit sharing		Amendment to the Patents Act by the Patents Amendment Act No. 20 of 2005 introduced the prior informed consent requirements of the 1992 Convention on Biological Diversity

Strategy objective	Intervention activities		Evidence
Utilise and commercialise IP	Develop national capacity to manage IP, especially IP from public-funded R&D: Establish an Intellectual Property Management Office to enhance protection of IP rights and ensure synergy with other policies		NIPMO established in 2010
	The obligation of institutions to protect IP developed from publicly financed research to be established: Establish TTOs at the various public research institutions		The 2017 NIPMO review report[24] covers the details of the TTOs
	Strengthen initiatives for the commercialisation of IP: Develop national capacity to manage technology licensing and commercialisation		The NIPMO report covers the development of this capacity
	Institutional practices in respect of benefit sharing, invention disclosure and minimum standards for institutional IP management should be standardised: Develop national capacity in benefit sharing, invention disclosure and minimum standards for institutional IP management		The NIPMO report covers the development of this capacity
	DST to take responsibility for the development of a national database of IP that arises from publicly financed research: A national database of IP that arises from publicly financed research is an important management tool to measure the current and future performance of the system		National database has been established by NIPMO and is updated regularly based on submissions by the TTOs
Reduce technology balance of payments	Increase patents per capita: Increase support for patent-generating activities including R&D expenditure and funds to support IP registration		The NIPMO report covers support for IP registration and seed funding
	The technology and innovation missions should develop South African controlled global IP: Implement the TYIP as a means of generating South African controlled global IP		This activity has not been possible due to weak industrial policy
	Provide specific financing as a means of securing important IP relating to inventions and designs: Intellectual Property Fund to be a programme within the Innovation Fund where it will secure its financing from the Innovation Fund structures		This action was implemented in the early years of the IPR Act but fell away when NIPMO was established
	Reduce costs of building an international IP portfolio: Signal to WIPO our increasing discomfort about the cost and inaccessibility of the global IP regime to publicly financed educational and research institutions in the developing world		It appears that this was an over-ambitious activity, and no material changes have been implemented

[24] Mustapha N, Khan F, Kondlo LO, Takatshana S, Ralphs GP, Whisgary D, Weyers J, Faul KL & Romanowska E. 2017. South African National Survey of Intellectual Property and Technology Transfer at Publicly Funded Research Institutions: Inaugural baseline study 2008-2014. Pretoria: Department of Science and Technology.

Strategy objective	Intervention activities		Evidence
Protect IK and IKS	Ensure that we protect indigenous knowledge and indigenous knowledge systems: Establish a working group for indigenous knowledge		The working group for is now operational and meets on a regular basis
Conserve South Africa's unique biodiversity	Ensure that we conserve South Africa's unique biodiversity		Not possible to assess since no specific activity was identified for this strategic objective

The overall assessment of the IP aspects of the NRDS/TYIP is that the high-level objective of creating a proper framework and enabling legislation for the effective management of IP arising from publicly financed research has been effectively implemented and operationalised. The initiative has grown from a zero base in 2006 to a R50 million per annum programme which has established (and supports) 25 TTOs in the higher education institutes and science councils, has trained a large cohort of IP experts, and provides funding for the registration of new IP/maintenance of IP portfolios.

The overall goals of the IP-related interventions – namely, to lessen reliance on imported technology, to reduce the deficit on the technology balance of payments, and to increase the economic impact of public-funded R&D – are as yet unrealised, or realised to only a minimal extent. The obvious difficulty with such an assessment is the demonstration of causality. Although little progress has been made with technology balance of payments, it may have been an even greater deficit in the absence of the strategy. The question of to what extent the IP strategy has been able to support the economic development of South Africa can only be answered in a more comprehensive study.

1.4 Monitoring, evaluation and learning

1.4.1 Introduction and overview

In our formative assessments of the NRDS and TYIP in Volume 2 we commented on the fact that both documents are weak as far as standard practice in M&E is concerned. In that discussion we showed that neither the NRDS nor the TYIP conform to good M&E practice in terms of intervention design, the formulation of clear and unambiguous goals and objectives, explicitly formulated theories of change, and appropriate and precise target-setting and indicator formulation.

The excerpts from the NRDS and TYIP below serve to remind us that the establishment of a proper M&E framework and system were indeed policy intents in both documents. We briefly comment on each.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Policy imperative		Evidence
Government needs an integrated R&D plan and consistent performance measurement in order to meet the requirements relating to the optimisation of government's investment in research and development. (NRDS: 64)		In theory, it might be said that the TYIP is the DST's response to this policy imperative, though it is not clear how consciously this imperative informed the content of the TYIP. The TYIP provides somewhat more detail on performance measures than did the NRDS, but inasmuch as its reach was almost entirely reserved for DST programmes and activities, the TYIP does not represent 'an integrated R&D plan'

Policy imperative		Evidence
A standard governance/reporting framework for all institutions with a strong R&D mandate must be developed by the Department of Science and Technology for consideration by Cabinet. (NRDS: 65)		This policy intent has not been effected. Generic governance standards have been developed and implemented across all government departments and entities through the agencies of the Auditor-General, the Department of Planning, Monitoring and Evaluation, and the Presidency, but these do not constitute the envisaged framework for reporting on R&D activities by public entities.

Policy imperative		Evidence
The respective line departments will set R&D goals and budgets for institutions reporting to them, within the standard framework described above. (NRDS: 65)		Inasmuch as no standard R&D reporting framework has been developed, this NRDS imperative has not been achieved. There may be instances where line departments have set targets for their respective public research entities, but there are far more examples where the needs of those entities have been neglected and their operational capacity denuded by poor decisions and unilateral budget cuts on behalf of the departments.

Policy imperative	Corresponding strategy or intervention		Evidence
Government will publish and annually update a three-year R&D Plan "in sync" with the MTEF, capturing its R&D vision as well as key targets and investments. (NRDS: 64)	The Cabinet Memorandum obliged the DST to "Work with National Treasury and other departments to implement the new Medium Term Expenditure Framework (MTEF) Science and Technology Expenditure Plan by 1 April 2005, for the 2006/07 MTEF Budget Cycle."		There is a significant disjuncture between the policy intent of the NRDS and the specific decision of Cabinet. The former envisaged a long-term, structural intervention in the form of a high-level, all-of-government R&D plan, whereas the practical implementation reduced this to cooperation between departments in informing the National Treasury on the content of the MTEF. With the dismantling of the science vote, the key instrument for the envisaged coordination of departmental R&D funding disappeared. But in March 2017, the Cabinet approved a recommendation from the DST that a 'budget coordination' framework and process be developed, though the details of this are still under development.

Policy imperative		Evidence
The DST is responsible for advising Cabinet on the overall health of science and technology in government, and monitoring research expenditure and innovation in industry. (TYIP: 29) • To effect this task, DST conducts an annual review, and presents a national expenditure plan to Cabinet. • New mechanisms to monitor important indicators such as patents, technology-trade mix, sector performance and technology balance of payments need to be introduced. • To encourage innovation, the DST will partner with provincial governments and facilitate the development of regional innovation systems plans.		Our assessment is that this policy intent has only been partially achieved. The DST has provided the required financial support to CeSTII to produce an annual R&D survey. This report has become an institutionalised and standardised feature of our STI landscape. Also, through NACI, the DST has initiated an annual STI Indicator Report, and regularly reviews the content and scope of this and the annual R&D survey. However, the Department has not been able to systematically link such reviews of national science, technology and innovation, to the allocation of budgets to relevant departments. There have been some attempts to establish inter-governmental collaboration with provinces, but systematic and significant programmes do not seem to have emerged specifically around regional innovation systems. The COFISA programme, funded in conjunction with Finland, established some short-lived innovation projects with provincial partners.

1.4.2 Assessment

Our predominantly critical comments on the M&E aspects of the NRDS and TYIP should be put into context. First, it is common knowledge that over the past two decades South Africa has witnessed the increasing institutionalisation of an M&E culture in the public sector. As early as 1999, a more concerted attempt at managing government performance emerged from the National Treasury and the office of the Auditor-General, who used the Public Finance Management Act of 1999 to regulate financial management in national government and provincial governments to ensure that all revenue, expenditure, assets and liabilities of those governments were managed efficiently and effectively. National Treasury's Framework for Programme Performance Information (FMPPI) sought to use a results-based management conceptual base with the structuring of departments' budgets around high-level budget programmes, and a framework for indicators and reporting. At this time the Presidency introduced a Government-wide Monitoring and Evaluation System (GWM&ES) in 2005, which was managed initially by an inter-departmental task team in the Department of Public Service Administration and later by the Policy Coordination and Advisory Service Unit located within the Presidency. Four years later, in 2009 and 2010 respectively, a Ministry and Department of Performance (later, Planning), Monitoring and Evaluation (DPME) were established. In 2011, an Evaluation and Research Unit was established in DPME to develop and run the evaluation system. The National Evaluation Policy Framework was approved by the Cabinet in November 2011. It foresaw a focus on priority national evaluations through a National Evaluation Plan, later widening to provinces with provincial evaluation plans and even later departmental evaluation plans.

Second, in a recent report submitted to NACI,[25] SciSTIP identified that more than 100 evaluation studies and reviews that pertain to the NSI have been completed since 1998. The earliest studies appeared in 1998 (SETI Review and the National Research and Technology Audit) and over the years included system-wide reviews, STI fields reviews and evaluations, evaluations of organisations (NRF, NACI, Centres of Excellence), reviews of funding instruments, and many more. The table below provides a summary overview of these studies.

Summary of completed reviews and evaluations of the South Africa STI system (1996-2019)

Level	Category of STI programme reviews	Count
National	System evaluations and reviews	13
	National institutional reviews	28
	Research centres and institutes	10
Sector-specific reviews		4
Scientific field	Scientific field reviews	27
Programmes	Science programme reviews	23

In our commentary on these reviews we concluded as follows:

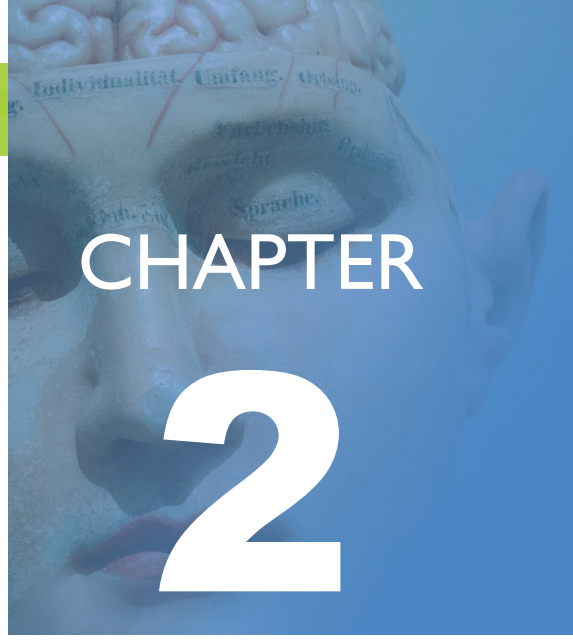
- There is quite a large number (given the short time-span) of system-level reviews (OECD, Ministerial reviews). Some of these reviews were undertaken within extremely short time periods which begs the question both of the coordination of these and whether the findings and recommendations of the different reviews were properly considered and addressed.
  - There is a clear predominance of institutional (organisational) reviews (such as the SETI-reviews) and scientific field reviews.
  - Although there are a substantial number of reviews of 'science' programmes (including funding and capacity-building programmes), there is a relative dearth of programmatic reviews in the broad field of technology and Innovation. It is, of course, possible that such reviews have been conducted but are not (easily) visible in the public sphere.
  - There are often long lag times in sector-specific reviews (time lag between adoption and implementation of strategy and first reviews). This raises questions about the 'absorptive' capacity in the system to manage some many reviews within short spaces of times.
  - Finally, the fact that these studies were commissioned by a relatively large number of departments and agencies (at least seven of them) in the same system, raises questions about the 'locus of control' of such reviews and whether there has been sufficient cross-sectoral and inter-institutional co-operation in this area.

M&E has indeed become a standard and pervasive feature of the STI landscape. However, our assessment of the policy intents in the NRDS and TYIP identifies three problems:

1. There was no coordination within the STI system of the commissioning and execution of M&E studies, with the result that
2. There was no systematic learning and uptake of these results to inform STI policy, strategy and planning, which in turn can be attributed to
3. A general lack of capacity and technical expertise in policy and strategy design and analysis.

It is encouraging that all of these problems or challenges are included in the 2019 White Paper as new policy intents. However, as our assessment has shown, the test now is whether these intents will be translated into actual practice. In 2019, SciSTIP developed and submitted – on request from NACI – a comprehensive and detailed M&E Framework for the South African STI. The implementation of a final version of this framework will go a long way to ensuring that more appropriate and coordinated evaluations and reviews are undertaken to inform policy and strategy design, implementation and impact.

[25] SciSTIP. 2019. *Report on a Monitoring and Evaluation Framework for the South African Science, Technology and Innovation System*. Stellenbosch: Centre of Excellence on Scientometrics and Science, Technology and Innovation Policy.



CHAPTER 2

HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY

2.1 Introduction and overview

The NRDS narrative on human resources development is couched in terms of developing and transforming the 'human capital for science and technology in the national system of innovation'. The NRDS identifies "the creation of a critical mass of SET human capital and a corps of researchers and future researchers" as one of three areas in which governments can target their investment (DST, 2002: 28). However, despite the strategic importance of defining goals and strategies regarding the development of human resources for S&T for South Africa, the NRDS ultimately does not explicitly state the need for the development and implementation of a dedicated human resources strategy. With the exception of a few (disjointed) references to desirable interventions and actions, there is no consolidated/singular strategy for human resources development in the NRDS. The references that are found in the NRDS are to:

- The establishment of a Women's Reference Group in S&T (reporting to the Deputy Minister of S&T), to promote gender-based issues in S&T, and complement relevant NACI activities;
- The establishment of centres of excellence;
- Science engagement activities to be up scaled to attract new students to careers in science;
- Consideration to be given to a specific programme to retain productive science and engineering educators and mentors in tertiary education, provided that they attract and develop young black and female students into postgraduate research; and
- Internationalisation initiatives: the need to attract talent to South Africa and the consequent need to liaise with the Departments of Home Affairs and Education (at that time still incorporating higher education).

At the end of the document, the NRDS included targets related to human resources as per the table below (see our discussion of these indicators in Volume 2).

Targets and achievement related to human resources in the NRDS

Indicator/Target	1990	Current	2012
Matriculants with university exemptions in Maths and Science	Not available	3,4%	7,5%
Proportion of SET tertiary students (% of all tertiary students)	20%	27%	30%
SET students (% of total age cohort)	6%	3.4%	12%
Number of SET practitioners per 10 000 of workforce	Not available	7	11

The TYIP follows a similar approach. It identifies human resource development as one of the overall strategic goals, but no specific or dedicated strategy is identified for development and implementation. The narrative is different from that of the NRDS in the sense that there is a much narrower focus on the development of the academic pipeline. The TYIP focuses on:

- A career path from BSc to researcher level to be established;
- The Masters and PhD intern programmes to become significant parts of government-funded research, with graduation targets being a significant part of the monitoring;
- Special interventions to attract potential researchers to senior degrees to be put in place;
- The production line of researchers to be monitored for bottlenecks; and
- Reviewing PhD curricula to strengthen innovation.

Although there is no explicit reference in the text to SARChI chairs, a table of indicators related to human resources development included a target of 210 research chairs to be established by 2018:

Human capital development actions and outcomes	*By 2018 South Africa anticipated that it will have* • *210 research chairs at universities and research institutions acress the country by 2010 and 500 by 2018 (58 were in place 2006)* • *About 6 000 PhDs produced per year in all SET disciplines by 2018* • *About 3 000 SET PhDs/doctorates produced by 2018* • *An optimal ratio of technicians commensurate with the country's requirements* • *A 1.5 percent global share of research publications (2006: 0.5 percent)* • *2 100 Patient Cooperation Trety International applications originating in South Africa (2004: 418)* • *About 24 000 patent applications at the South Africant Patent Office (2002: 4 721)*

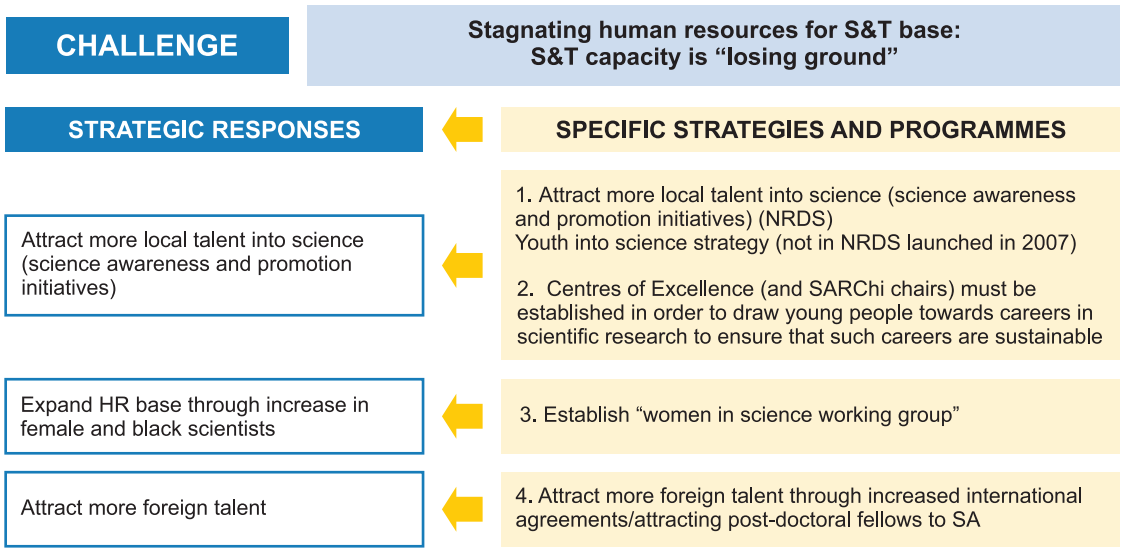
It would only be eight years later that an integrated and consolidated strategy for human resources development for the STI would be published by the DST; namely, the *Human Capital Development Strategy for Research Innovation and Scholarship* of 2016. This document brings together all of the individual strands related to human resources for S&T in the NRDS and TYIP, but also some very new components. We return to a discussion of this strategy in more detail at the end of this chapter.

Our reading of the NRDS and TYIP suggests that these two documents had three general strategies in mind when analysing the challenges related to human resources for S&T. These are:

- Strategies related to *expanding* the human resources base through broadening the indigenous capacity (local talent) in the country;
- Strategies related to expanding the human resources bases through attracting foreign talent to the country; and
- Strategies related to *transforming* the human resources base to make it more inclusive of race and gender.

The figure below elaborates on each of these 'strategic responses' and the associated strategies. We discuss each of these strategic responses in greater detail below.

The HR challenge and NRDS strategic response



It is interesting that the text in the NRDS devotes extensive coverage to the first strategy (attracting more local talent into science) in the context of expanding existing public understanding and science engagement initiatives. This discussion also includes references to transforming the pool of students to include more women and black learners and students.

> There is *a need to massify a number of public understanding and engagement activities using the Institute for the Promotion of Science and similar structures. The programme massification would include out-of-school maths and science programmes to increase the number of matriculants achieving university entrance in Mathematics and Science (particularly women and other previously disadvantaged groups) and enhanced use of the media to promote mathematics, science and computing subject choices among learners. (p78)*
>
> *Very innovative programmes are necessary to move far beyond the current 3 000 black matriculants with passes in higher grade Mathematics. In addition, considerable attention must be given to increasing the number of girls taking mathematics, science and computing subjects through their school careers and having in place enabling mechanisms for women to enter tertiary studies in science, engineering and technology. It will be necessary to increase "out-of-school" programmes to support mathematics, science and computer education. …. In addition, specific consideration should be given to incentivising schools to produce more black and female Mathematics and Science matriculants at the higher grade. For example, private schools that successfully produce higher-grade Mathematics and Science matriculants from designated groups could be retrospectively paid the equivalent of the education subsidy. (p55)*
>
> *To attract young people to science and engineering it is necessary to communicate very clearly that these disciplines have a future and that those who enter them are likely to have fulfilling and relatively prosperous careers. We believe our ability to attract young people to careers in science and technology will depend on our adoption of new technology mission that are, designed for a democratic, inclusive South Africa in the context of our governmental obligations* through SADC, NEPAD and the EU. (p56)

The NRDS committed the DST to converting the Foundation for Education in Science and Technology (FEST) into the Institute for the Promotion of Science (p17).

As is clear from the above, no mention is made of a specific strategy. However, four years later in 2006 the DST published the Youth into Science Strategy. While this strategy is not explicitly mentioned in the NRDS, it is linked to addressing the challenge of human capital development identified in the NRDS. The long-term goal of the Youth into Science Strategy is to develop high level skills required for the production of the next generation of productive and representative researchers. The strategy is targeted at school-going youth and undergraduate students in science, technology, engineering and mathematics (STEM) aged 14-35, focused on those from disadvantaged backgrounds (especially those with disabilities, black students, and young women). The two strategic goals of the strategy are formulated as enhancing S&T literacy, and nurturing youth talent and potential for science, engineering and technology-based careers

The brief references to the Centres of Excellence and South African Research Chairs programmes in the NRDS and TYIP are made within the context of the narrative on attracting young scientists to careers in science. It is interesting to note that both these programmes – which are in essence programmes to stimulate and maintain excellence in knowledge generation – are discussed within the context of strategies to build the human resources capability of the science system.

The only reference to the strategic importance of internationalisation in either the NRDS or TYIP is made within the context of attracting foreign talent (increase in post-doctoral fellows is specifically mentioned). There is no reference to an international strategy or programme in either document. However, given the considerable resources that have been expended on a wide range of bilateral and multilateral S&T agreements in support of increased international (especially African) cooperation and collaboration, the team has produced a short dedicated review of this theme (Volume 5: Annexure 6).

Given the importance of building, expanding and transforming the human resources base for S&T in South Africa, the question must be asked as to why neither the NRDS nor the TYIP included a singular and dedicated strategy for human resource development for S&T. The most plausible explanation is that at the time the authors of the NRDS were drafting the strategy, other developments in this arena were in fact becoming more visible and receiving attention. A first draft of the Human Resources Development Strategy (HRD) was published in 2001. Other relevant policy and strategy documents that related to human resources development issues were the National Plan for Higher Education (2001); the Accelerated and Shared Growth Initiative for South Africa (AsgiSA) and the Joint Initiative on Priority Skills Acquisition (JipSA), both launched in 2006; as well as the establishment of the Human Resource Development Council in 2010.

The need for an HRD strategy had originally been raised in the 1996 White Paper on S&T. The White Paper tied itself closely to the imperatives and intended outcomes of the Growth and Development Strategy in terms of HRD; in particular, “investing in people as the productive and creative core of the economy”, and an HRD strategy that includes aspects to do with training, the restructuring of education and social partnerships (DACST, 1996: 38). Accordingly, DACST was assigned the responsibility of “bringing the perspective of S&T to each of these programmes” (ibid.).

But it would only be 13 years later that this would come into effect when in the 2009 version of the HRD Strategy a clear division of labour between DST and DHET regarding strategies and programmes related to human resources development were made. In particular, the DST would be responsible for the implementation of commitment 6 of the strategy, which deals with the improvement of the country’s science, technology and innovation capability, as well as ensuring enough national research capacity. It is also responsible for delivering on Strategic Goal 3 and Programme 3 of the revised 2017 HRD Strategy, which deals with research and technological outcomes. The DHET is responsible for all post-schooling education and training in the country and for the implementation of 75% of the 2009 HRD Strategy commitments (commitments 1, 2, 4, 5, 6 and 8), as well as Strategic Goals 2, 3 and 4 and Programmes 2, 3 and 4 of the revised 2017 strategy. These deal with access and quality of post-school education and training, higher education and training, and the production of skilled people for the economy. The DHET also manages the HRDC Secretariat through the office of the responsible Minister.

It is worth pointing out that the funding programmes targeting the development of human resources for S&T – which is one of the major mandates of the NRF – were ongoing. Various initiatives were launched by the precursors of the NRF (the Foundation for Research Development and the Centre for Science Development) in the late 1980s to develop human capacity in R&D. With the establishment of the NRF in 1999, many of these were consolidated and a number of new initiatives were also launched. The NRF scholarship and bursary programmes continued and expanded, and various dedicated funding instruments were introduced to expand and transform the human capital base (e.g. Thuthuka).

The omission of a dedicated HR strategy for S&T in the NRDS, and especially the TYIP, however, was in our view an oversight. Even though various initiatives were being planned and implemented, none of them were driven directly by the DST. Also, with many diverse stakeholders operating in this space, it was even more important that a coordinated and dedicated strategy for the science system should have been developed.

With the publication of the revised version of the HRD Strategy in 2009 the time was right for DST to invest in the development of a dedicated HRD strategy for S&T. This did indeed happen insofar as work on a new strategy document commenced in 2009, evidently championed by the then Minister of S&T, as indicated in the

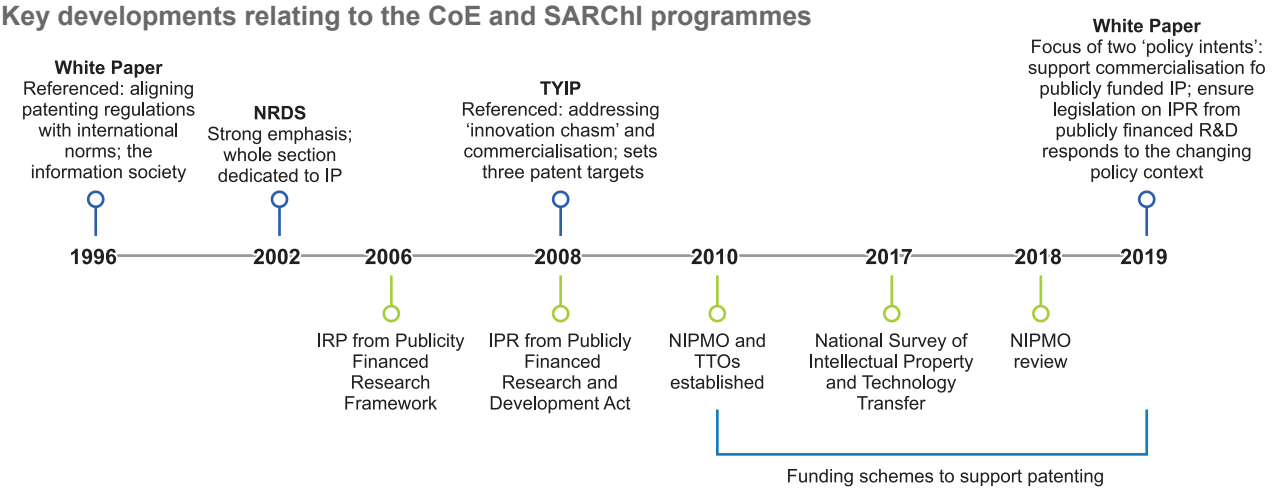
acknowledgements section of the 2016 HCD for RIS Strategy document (DST, 2016: 2). But initial attempts to draft the HCD for RIS Strategy were clearly unsuccessful as a revised version was only circulated in 2012 for external comment.[26] The final version of the HCD for RIS Strategy would only be published in 2016. We return to a discussion of the strategy at the end of this chapter.

2.2 Two flagships initiatives: The Centres of Excellence and SARChI programmes

The NRDS identified the need to create 'centres and networks of excellence' in S&T, including in the social sciences, as a key component of the human capital and transformation dimensions of government policy. This is re-emphasised in the TYIP in which it is envisaged that such centres will stimulate sustained distinction in research while simultaneously generating highly qualified human resource capacity in order to impact meaningfully on key national and global areas of knowledge. There is no specific mention of a research chairs initiative in the NRDS other than a reference to an initiative in Canada to counter the migration of scientists to the US; namely, the creation of 2,000 university chairs in science and engineering over a five-year period. In the TYIP, under the heading 'Human capital and knowledge generation', reference is made to a proposed research chairs initiative in South Africa; specifically, the establishment of 210 research chairs in public universities and research institutions by 2010 and 500 by 2018.

The figure below highlights key developments relating to the CoE and SARChI programmes. As can be seen, two external reviews were conducted of the CoE programme in 2009 and 2013,[27] and an external review of the SARChI programme in 2012.[28]

Key developments relating to the CoE and SARChI programmes



Since these two initiatives were explicitly referenced in the NRDS and TYIP we conducted more comprehensive reviews of each (Volume 5: Annexures 7 and 8). We provide a summary of the main findings of these reviews below.

2.2.1 The CoE Programme

According to the 2012 DST/NRF *Framework for the Establishment of DST-NRF Centres of Excellence Managed by the Knowledge Fields Development (KFD)* document, "CoEs are physical or virtual centres of research that concentrate existing research excellence and capacity and resources to enable researchers to collaborate across disciplines and institutions on long-term projects that are locally relevant and internationally competitive in order to enhance the pursuit of research excellence and capacity development" (DST/NRF, 2012: 4). The five key performance areas (KPAs) of the CoEs are: (1) Research/knowledge production, (2) Education and training, (3) Information brokerage, (4) Networking, and (5) Service rendering.

The DST/NRF CoE funding instrument was launched in 2004 with the establishment of seven CoEs. Since then, three additional CoEs were established between 2009 and 2013 and five new CoEs established in 2014. By 2019, 15 CoEs had been established.

[26] Johann Mouton was one of the reviewers requested to comment on a draft version.
[27] Cozzens SE & Woods DR. 2009. *Review of the DST/NRF Centre of Excellence (CoE) Programme*. Pretoria; Bawa A, Alper H, Cozzens S, Krishna V & Woods DR. 2013. *Review of the DST-NRF Centres of Excellence Programme (2013) Final Report*. Pretoria.
[28] NRF. 2012. *Five Year Review of the South African Research Chairs Initiative (SARChI)*. Pretoria: National Research Foundation.

DST/NRF Centres of Excellence

Year est.	Name	Host(s)
2004	DST-NRF Centre of Excellence for Biomedical Tuberculosis Research (CBTBR)	UCT, SU, Wits
	DST-NRF Centre of Excellence Birds as Keys to Biodiversity Conservation[29]	UCT
	DST-NRF Centre of Excellence for Invasion Biology (CIP)	SU
	DST-NRF Centre of Excellence in Tree Health Biotechnology (CTHB)	UP
	DST-NRF Centre of Excellence in Catalysis (C*change)	UCT
	DST-NRF Centre of Excellence in Strong Material (SM)	Wits
2006	DST-NRF Centre of Excellence in Epidemiological Modelling and Analysis (SACEMA)	SU
2008	The National Institute for Theoretical Physics (NITheP)	SU, UKZN, Wits
	DST-NRF Centre of Excellence in HIV Prevention (CAPRISA)	UKZN, UCT, UWC
2013	DST-NRF Centre of Excellence in Palaeosciences (CoE-Palaeo)	Wits
2014	DST-NRF Centre of Excellence for Integrated Mineral and Energy Resource Analysis (CIMERA)	UJ
	DST-NRF Centre of Excellence in Human Development (CoE Human)	Wits
	DST-NRF Centre of Excellence in Food Security (FS)	UWC and UP
	DST-NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy (SciSTIP)	SU and TUT
	DST-NRF Centre of Excellence in Mathematical and Statistical Sciences (MaSS)	Wits
2018	DST-NRF Centre of Excellence in Indigenous Knowledge Systems (CIKS)	UKZN

There are no clear overarching goal statements for the CoE Programme. This was specifically noted by the 2013 CoE review panel: "While the founding documents indicate what is expected of the Centres, how they will be measured and how they are expected to contribute to the mandate of the NRF, there isn't a clear statement about the purpose of the Programme. For instance, should the Programme (and hence, the Centres) resonate with the NDP or with the national grand challenges? This is a question about the meta-narrative of the Centres of Excellence Programme" (Bawa et al., 2013: 6).

Although it is not labelled as 'a theory of change', such a theory can be inferred from the definition of CoEs in the exposition of the strategic context of the CoE Programme in the 2012 Framework Document. In terms of this theory (confirmed by the experience in Australia, Canada and the US), a **national programme** to **concentrate existing capacity and resources** in physical or virtual research centres will bring about change in a number of respects, including, (a) enhanced **research activity,** (b) increased **collaboration** across disciplines and institutions, (c) **long-term** research projects, (d) **locally relevant** and **internationally competitive** research projects, (e) the **pursuit of excellence**, and (f) **capacity building**.

In the tables below, we provide a summary assessment of achievement against the five KPAs of the CoE programme, as well as three additional categories identified by the review panels. The evidence for our assessments in all categories is derived from the 2009 and 2013 review reports.

Achieved

Partially achieved

Not achieved at all

Not possible to make a judgement

[29] Originally established in 1959

Assessment of implementation of the key performance areas of the CoE Programme

Strategy objective	Interventions		Comments
Research	The main activity of a CoE is research		The production of research is at a very substantial level and there has been a significant improvement in the impact factors.
Education and training	Human capital development will focus on support for honours, masters, doctoral students, post-doctoral fellows, interns and research staff		The graduation of masters and doctoral students is at a very substantial level. The Centres are also on a good trajectory in terms of their student graduation rates.
Information brokerage	CoEs are to provide access to a highly developed pool of knowledge, maintaining data bases, promoting knowledge sharing and knowledge transfer		Although new connections for Centre researchers were stimulated, there is under-utilisation of the research potential of the CoEs in addressing global areas of knowledge.
Networking	A CoE is expected to actively collaborate with reputable individuals, groups and institutions. Equally, it must negotiate and help realise national, regional, continental and international partnerships		Most of the Centres work as outstanding networks bringing together individuals from different institutions and research groups.
Service rendering	A CoE is to provide and analyse strategic information for policy development, as well as other services including informed and reliable advice to government, business and civil society		While the CoEs provided advice, information and knowledge to various stakeholders (government and statutory bodies, industries, NGOs, etc.), the balkanisation of the actions of government departments (evident in the lack of coordination and absence of attempts at synergistic funding) remains a serious impediment.

Assessment of implementation of the additional categories identified by review panels

Identity and awareness		The place of the CoE Programme in the NSI is not well known. There was not sufficient knowledge about the CoE Programme except in the narrow constituency in which the Centres operate.
Management and leadership of the CoEs		Centre directors felt that their annual performance reports, in the key performance areas (including management), were reasonable. Leaders serving in other different roles (board members, research managers) meet their obligations.
NRF management of the CoE Programme		There are deep concerns among the CoE directors about the management of the CoE Programme by the NRF. Main concerns include inordinate delays in important communications and the fragmentation of the administrative systems, and a lack of scientific engagement and programmatic leadership on the part of the NRF.

2.2.2 The South African Research Chairs Initiative (SARChI)

The SARChI programme was established by the DST in 2006/07 as a strategic intervention designed to attract and retain excellence in research and innovation at South African universities. The NRF was charged with implementation and oversight of SARChI. The support for the SARChI was initially aimed at establishing Tier 1 Chairs aimed at attracting scientists at the forefront of their field. Tier 2 Chairs were later introduced to accommodate established researchers who could advance to Tier 1 in 5-10 years.

A five-year review of the SARChI Programme was conducted in 2012 to assess the conceptualisation, implementation and management of SARChI and its overall performance in terms of its mandate and objectives,

and to make recommendations for the future to enhance both SARChI as a programme and the performance of the Chairs. According to the review report (NRF, 2012: iii):

> *A base grant, subject to annual inflationary increase, of up to R2.5 million per annum was made to each Tier 1 Research Chair to cover the salaries of Chair holders, postdoctoral and student awards, research operating costs, and small equipment requirements. Improvements to the SARChI programme over the review period in response to stakeholder feedback included: i) introduction of Chairs at Tier 2 level for researchers on an upward trajectory, generally under the age of 40, with the potential to achieve Tier 1 status in the next 5-10 years; and ii) eligibility for appointment at Tier 1 level of candidates from abroad who are willing to spend at least 50% of their time at a South African university.*

At the time of the 2012 review, the programme had delivered 89 fully operational Chairs over the five-year period. Thus, the TYIP's target of 210 Chairs by 2010 had not been achieved. Nevertheless, the review report noted: "Despite the slower-than-expected delivery, the initiative has been effective, efficient and produced a number of results and benefits" (ibid.). The TYIP had set a target of 500 Chairs by 2018. However, according to the 2017/18 NRF annual report, a total of only 226 research chairs had been awarded by 31 March 2018, of which 215 were operational. Based on data provided by the NRF Directorate for Research Chairs and Centres of Excellence, by February 2020, a total of 246 Chairs had been awarded, of which 232 were operational, three were not operational, and 11 had been rescinded, phased out and/or ended their funding cycle.

Review questions posed by the NRF to the 2012 Review Panel:

1. Has SARChI led to the attraction and retention of world-class researchers?
2. Are there more research students because of SARChI?
3. Has SARChI reversed the research output decline?
4. Has SARChI improved the capacity of HEIs and related entities?
5. Has SARChI stimulated strategic research across the knowledge spectrum?
6. Has SARChI increased research excellence?
7. Has SARChI created research pathways for high-quality young and mid-term researchers?

In the table below we assess the achievements/progress made towards implementation of the SARChI programme based on the revised goals and objectives as per the NRF Call for Applications in 2011.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Implementation scorecard for the SARChI programme, based on 2011 goal and objectives

	Activity		Evidence
Goal (2011)			
To strengthen and improve research and innovation capacity of public universities for producing high quality postgraduate students, research, and innovation outputs	By 31 March 2018 a total of 226 research chairs were awarded, of which 215 were operational. Of the 215 operational chairs, 33% were in human and social dynamics, 18% in the industry sector of the bio-economy, 16% in the health innovation sector of the bio-economy, 13% in biodiversity, 7% in astronomy and 3% in the agriculture sector of the bio-economy.		NRF annual report 2018 (p14 and p74)

	Activity		Evidence
Objectives (2011)			
Expand the scientific research and innovation capacity of South Africa	In 2017-2018 SARChI directly supported 1,147 postgraduate students (52% females and 61% black) through grant-holder linked bursaries.		NRF annual report 2018 (p14)
Improve South Africa's international research and innovation competitiveness while responding to social and economic challenges of the country			
Attract and retain excellent researchers and scientists			
Increase the production of Masters and Doctoral graduates			
Create research career pathways for young and mid-career researchers, with a strong research, innovation and human capital development output trajectory			

The 2012 Review Panel concluded that:

> *(ppiii-iv) Chair holders, host Universities, research students and other stakeholders are very enthusiastic about the SARChI programme and the host of new opportunities it brings. The implementation of the programme has seen significant attraction and retention of talented researchers, increasing numbers of graduate students (masters, doctoral and post-doctoral) and an increasing flow of publications including those to prestigious journals. In addition, the programme has resulted in the development of significantly improved research capacity at host institutions and created and reinforced nodes of excellence at the major research universities, as well as at a number of newer and/or historically disadvantaged institutions. Some issues remain about processes that require addressing. Further enhancements to the programme, however, are required to consolidate and build on the success achieved so far.*
>
> *(p26) The Review Panel has been greatly impressed by much of what it has seen and heard. The South African Research Chairs Initiative has been an imaginative and largely successful innovation in the quest for increased knowledge production and the incubation of the next generation of researchers and scholars. In particular:*
>
> - *SARChI is contributing to the attraction and retention of world-class researchers in South Africa and has created nodes of excellence at various higher education institutions across the country, and*
> - *Chair holders, host universities, research students and other stakeholders are very enthusiastic about the SARChI programme and the opportunities it brings*
>
> *Overall, the Review Panel judged the design and management of SARChI to be generally sound. The programme direction continues to be relevant, coherent and consistent with policy aims.*

2.3 The Human Capital Development Strategy for Research Innovation and Scholarship

2.3.1 Context, overview and strategic objectives

The development of the HCD Strategy for RIS was initiated in 2009 but only appeared in 2016. Although we present a fairly detailed assessment of the strategy in Volume 5 (Annexure 9), it is important to point out that (a) the document is not a (forward-looking) strategy in the strict sense of the word; and (b) according to our knowledge was never actively championed and implemented throughout the NSI. As to the former: close reading of the document shows that, although comprehensive and detailed, it reads like a post hoc integration of mostly existing strategies and interventions that have either been identified in previous documents or were already being implemented by key actors in the system. Because of this, it cannot be reviewed as a forward-looking strategic document which awaits an implementation and/or action plan. This also, perhaps, explains why it was never actively promoted and implemented as a strategy.

Having said this, our review shows that it is a useful document – precisely because of its attempt to bring together and integrate various HRD-related initiatives under an explicit conceptual framework. The strategy identified six high-level strategic objectives (and 36 subsidiary objectives).

Goals and strategic objectives of the HCD Strategy for RIS

Mission	This strategy is intended to provide a holistic framework for increasing the number of active researchers and enhance research and innovation skills and outputs in order to improve South Africa's international competitiveness as a producer of scientific knowledge and innovation in support of national socio-economic development	
Strategic objectives	1	Increase the number and improve the demographic of students in masters and doctoral research degrees
	2	Increase the research productivity and training capacity of supervisors and researchers
	3	Enhance the role of science councils in research training and scientific production
	4	Increase R&D support for science and technology domains to maximise impact on innovation and economic development
	5	Grow research and innovation output through improved coordination and joint intervention with government departments
	6	Foster international partnerships in support of improved research and innovation skills in South Africa

2.3.2 Assessment

Our assessment of the six high-level objectives and associated subsidiary objectives is summarised below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation of the HCD Strategy for RIS

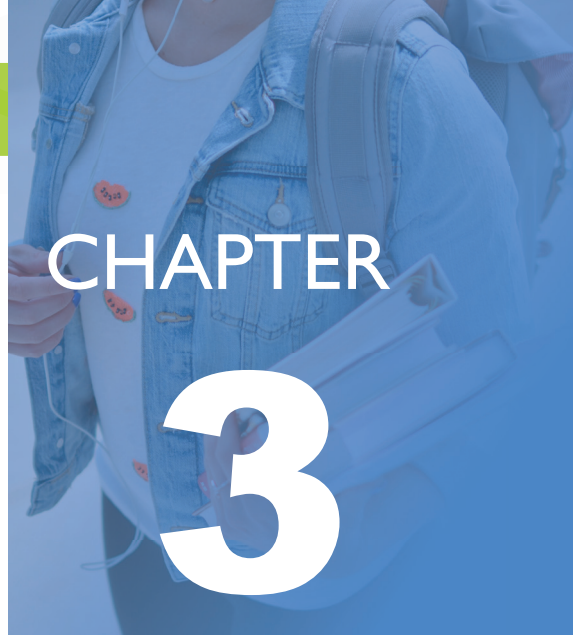
Strategy objective	Interventions	Assessment
Improve the number and demographics of students with master's and doctoral research degrees	Continue to increase DST's funds available for student bursaries	
	Increase number of enrolments in postgraduate studies	
	Conduct a national review of doctoral programmes to ensure strong quality assurance measures	
	Investigate feasibility of guaranteeing doctoral bursaries upon enrolment for masters studies	
	Improve completion and throughput rates particularly of doctoral students	
	Commission a survey to understand low master's and doctoral enrolment rates of black South African students	
Increase the research productivity and training capacity of supervisors and researchers	DST to ensure support for a significant scaling up of South Africa's postdoctoral cadre	
	Create career awards for recent postdoctoral researchers	
	Commission a strategic analysis of fields in which postdoctoral students will have strongest impact	
	Strengthen support for emerging researchers by increasing investment in the Thuthuka programme	
	Continue support of Next Generation of Academics for South African Higher Education Initiative	
	Compile a compendium of best practice regarding institutional policies for universities to achieve higher qualification levels for staff	
	DST and NRF to ensure new appointments of SARChI chair holders that become vacant	

Strategy objective	Interventions	Assessment
	Scale up CoEs in the medium to long term and examine establishing a new programme of large national institutes	
	Enhance arrangements promotion inter-institutional cooperation to strengthen supervisory capacity	
	Consider joint doctoral programmes as a way of improving doctoral graduations	
Enhance the role of science councils in research training and scientific production	Pursue a systematic framework for enhancing science councils' involvement in postgraduate training	
	Support incentives to encourage the use of science councils' infrastructure and supervisory capacity for training of postgraduate students	
	Strengthen supervisory capacity through supporting of co-supervision models	
	Support and strengthen development programmes for entry-level positions	
	Establish a systematic programme to absorb unemployed masters and doctoral graduates	
Strategically increase R&D support for science and technology domains to maximise their impact on innovation and economic development	Advance enrolments in postgraduate studies in SET fields through postgraduate study awards programmes	
	Improve planning and support for provision of research and innovation infrastructure	
	Ensure accessibility and use of cyberinfrastructure by universities	
	Engage higher education sector to promote public-private partnerships at institutional level	
	International benchmarking of low conversion rates from master's to doctoral studies in engineering disciplines	
	Strengthen engineering schools and universities of technology to enhance PhD level research and training activities	
Growing research and innovation output through improved coordination and joint interventions with other government departments	Develop complementary approaches DST/NRF programmes for research development and support	
	Continue DST and dtipartnership to enhance collaboration and strengthen synergies	
	Continue increased levels of public funding to strengthen the pipeline of researchers	
	Establish level of research productivity and set benchmarks	
Fostering international partnerships in support of expanded and improved research and innovation skills in South Africa	DST to pursue cooperation agreements to attract recent doctoral graduates to South Africa	
	Continue earmarking funds for partnerships between the DST/CSIR and multinational corporations for joint ventures	
	Strengthen collaborations with universities and research institutions on the African continent	
	Replicate successful international partnerships in improving staff qualifications at doctoral level	
	Encourage the establishment of bilateral research chairs	

2.4 Concluding assessment on human resources for science and technology

Our final assessment produced a fairly mixed scorecard. Some progress has been made in terms of increasing the production of postgraduate students, while there has also been an expansion of the funding base to masters and doctoral students. The scaling up of the CoE and SARChI programmes has largely been successful. However, we found little evidence of systematic efforts to improve the pipeline of students, especially with regard to increasing throughput and conversion rates. Many of our 'blue assessments' in the review (interventions where we were unable to make an assessment based on available evidence) pertain to efforts by the DST to engage other government departments and science councils to strengthen collaboration and partnerships, both with local institutions (HEIs and science councils) and institutions on the African continent.

The HCD Strategy for RIS is a comprehensive strategy that outlines a range of activities and interventions which include partnering efforts of the DHET and the NRF among others. As indicated above, the strategy is best understood as the first integrated compilation of gains made vis-à-vis building human capacity over the last decade, while also proposing some new strategies, particularly in areas of collaboration and establishing bilateral partnerships. Although the strategy is comprehensive, many of the activities and interventions outlined are not sufficiently well-formulated and often repetitive. Little distinction is made between short- and longer-term objectives and, in most cases, measurable targets are not provided, which makes the assessment of interventions problematic. A revised, or future, strategy for human capital development should build on the existing strategy, but improvements should be made in terms of clarifying, and making more specific, some of the broader proposed interventions, while including measurable targets against which progress can be measured.



SCIENCE AND INDIGENOUS KNOWLEDGE SYSTEMS

3.1 Introduction

As one would expect in national STI strategies and plans, both the NRDS and TYIP re-affirm the value and importance of the production of world-class science – both for its own sake as well as for its utilitarian value. The former – the pursuit of excellence in science for the sake of science – has been the main imperative of the scientific enterprise since its earliest origins. Scientists pursue the production of truthful and credible knowledge in order to increase and deepen our understanding of our physical and social world. The latter is typically linked to the value of science in providing the basis or platform for technological development and innovation, and thereby ultimately to produce positive economic and social outcomes.

Three main imperatives regarding scientific research are discussed – in varying degrees of detail – in the NRDS and TYIP:

- To *increase and grow the scientific knowledgebase* of the country. This imperative is explicit in the emphasis (especially in the TYIP) on the importance of South Africa transitioning to a knowledge economy. It is also implied in the inclusion of quantitative indicators and targets about increasing the quantum of our scientific output (e.g. to increase the share of South Africa's research publication output to 1% of world output by 2015).
- To *transform the research productive capability* in South Africa. This imperative is a main theme in the 1996 White Paper and various subsequent national policy documents (e.g. the 2001 National Plan for Higher Education) and is a direct response to the legacy of apartheid science. The narrative in the NRDS around the 'frozen demographics' captures this imperative and specifically the need to include more black and women scientists and researchers in the production of knowledge.
- To *increase international research collaborations and expand networks*. This is also reflected in the imperative to attract foreign talent to the country and hence the investment in international cooperation and collaboration initiatives.

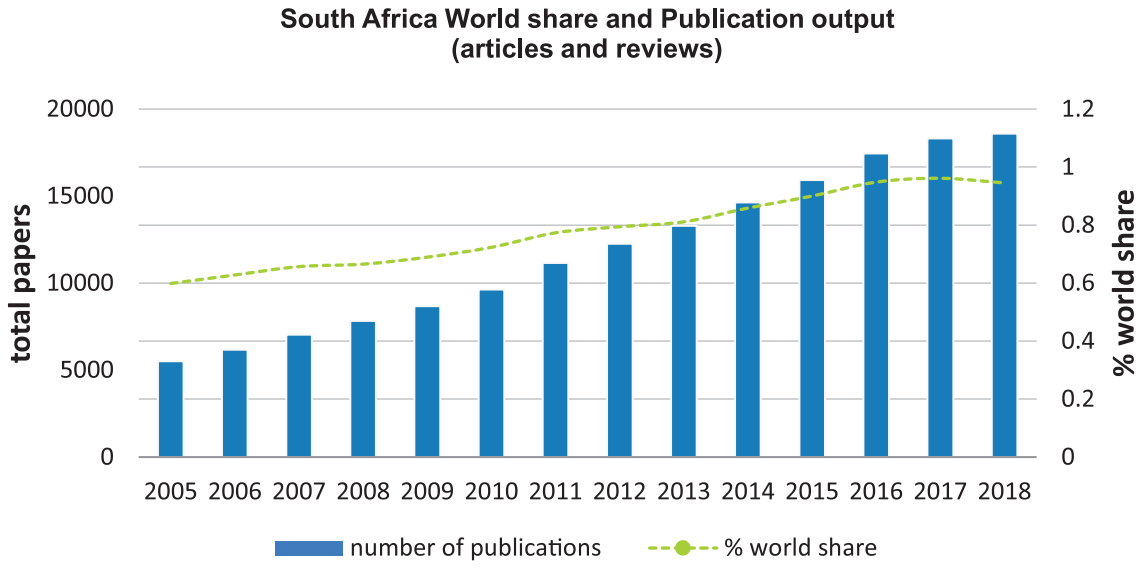
As far as the first imperative is concerned, this is one of the few cases in either document where a target is set. While the TYIP does not explicitly define what are considered to be research outputs, it states that "the principal qualitative measure of knowledge production is the output of original articles published in scientific journals" (DST, 2008: 26). It provides a baseline of 0.5% for 2002 and a target of 1% for 2018. A recent bibliometric analysis conducted by CREST, using the Web of Science database (defining research outputs as articles and reviews

and using full-paper counting), provides the time series data. The most recent data for 2018 shows the world share of publications at 0.95% fell just short of the target of 1% (table below). But as the figure below shows, there has been a steady increase in world share over the past 13-14 years.

South Africa's world share of publications (Web of Science, 2002-2018)

Source	Indicator	2002	2010	2011	2012	2013	2014	2015	2016	2017	2018
TYIP	Global share of research output	0.5									(1)
Web of Science	World share of publications	0.5	0.72	0.77	0.79	0.81	0.86	0.90	0.95	0.96	0.95

South Africa's world share and publication output (Web of Science, 2005-2018)



In our recent assessment of *The State of the South African Research Enterprise* (Mouton et al., 2019) we provided a detailed analysis of South Africa's research performance. We showed that this substantial and steady increase in our world share of publications occurred at the same time as our increased international scientific visibility in most fields (citation impact) as well as international collaboration. But this trend also happened at a time when the human resource base for S&T did not expand. So, what were the main causes or drivers of the increased publication output by the South African science system?

- It is important to understand that nearly 90% of the scientific publications produced by our science system is produced by the universities. The science councils, national research facilities, government research units and the private sector only contribute 10% to this output – and this share has been declining significantly over the past 20 years.
- The universities have benefitted hugely from the introduction of the revision of the DHET research output policy in 2005. The revised policy consisted of substantial incentives to universities to produce more research publications (articles as well as book, book chapters and published conference proceedings) as well as research masters and doctoral graduates. The increase in these subsidy unit amounts (to an average of around R110,000 over recent years) for a single-authored article in a DHET-accredited or recognised journal list, has resulted in steep increases in publication output by university academics, post-doctoral fellows and students since 2008. More recent data indicate that output levels have started to reach a ceiling.
- Analyses by CREST of individual universities in recent years have shown that the increased output is primarily owing to larger proportions of academics at most universities publishing (which is also related to a commensurate increase in the number of academic staff with PhDs), more output by post-doctoral fellows at universities (the higher education system has seen a steady increase in the number of post-doctoral fellows, reaching more than 2,700 in 2018) and finally, increased contributions by doctoral students, who are publishing articles based on their theses or doing their PhDs by paper.

But, as we have indicated above, these increases have not occurred because of the expansion of the academic and scientific capacity in the system. On the contrary, the system has lost some capacity (the number of FTE researchers in the science system has started to decline in recent years). For these reasons we believe that we should not expect that the increase in world share will necessarily continue. South Africa operates in a highly competitive global science system where a number of the bigger countries (most notably China and India) are increasing their country shares of publications much faster than other countries. In order for South Africa to maintain even around 1% of the global publication output would require imaginative new strategies and additional funding support and – most importantly of all – the expansion of the human resource base for S&T.

3.2 Steering the science system

A key science policy question is to what extent a national government (and its STI agencies) should steer the national science agenda through priority-setting and dedicated and ring-fenced resource allocation; in other words, which scientific fields and disciplines should receive 'priority treatment' through additional and earmarked funding. Although most national funding agencies would typically aim to find a balance between earmarked and open funding so as to ensure that fundamental (even blue skies research) can be undertaken without the demands of application or utility and other policy priorities often resulting in increased steering of public monies to priority fields such as those linked to the MDGs and SDGs.

There are two narratives in the NRDS which relate to this theme; namely, that we should invest in those scientific areas where we have a *geographic advantage* (astronomy, biodiversity, palaeontology and Antarctic research), and a *knowledge advantage* (such as indigenous knowledge).

The first narrative related to our 'geographic advantage' was already prominent in the 1996 White Paper and subsequently reaffirmed in the NRDS and TYIP:

- The two astronomical facilities each have sound research records and are able to take advantage of the desire of northern hemisphere researchers to access quality data from the southern skies (DACST, 1996: 62).
- Goal statements blend astronomy and space science, including satellite engineering. The goals are anchored in SGA: "One way to achieve national excellence is to focus our basic science on areas where we are most likely to succeed because of important *natural* or knowledge advantages. In South Africa, such areas include astronomy, human palaeontology and indigenous knowledge" (DST, 2002: 18).
- The TYIP essentially repeats the NRDS: "Astronomy, palaeontology, antarctic and marine science, biosciences, social sciences, earth systems and environmental sciences. These missions exploit South Africa's 'living laboratories' of local resources and geographic advantage" (DST, 2008: 38).

The second narrative of our 'knowledge advantage' is not as clearly articulated as the first. The 'areas' identified under the heading of a 'knowledge advantage' are – at least on the face of it – areas where we have a *technological* advantage rather than a *scientific* advantage (deep mining technology, diseases of poverty, the African integrated approach to HIV/AIDS vaccine development, microsatellite engineering, encryption technology and fluorine technology). Ironically, the S&T base of the last three areas can be traced to either defence and/or nuclear research, which had been developed in the 1970s and 1980s.

Perhaps a more 'charitable' interpretation of the second narrative is that our technological advantage in these areas can in fact be traced back to strengths in certain scientific areas. Stated differently: in each case it would be possible to show how the current (2002) technological advantage is the accumulation of a long tradition of dedicated and accumulative scientific research. An example: the technical expertise in 'deep mining technology' (although not explicitly referenced like this) clearly built on a long tradition in geological and mining engineering research in the country.

Given the priority given to the scientific fields discussed under these headings, dedicated strategies for astronomy, palaeosciences and marine and antarctic sciences have subsequently been developed and we have accordingly completed individual reviews of these (Volume 5: Annexures 10-12). In addition, a review has also been completed for the Indigenous Knowledge System Policy (Annexure 13).

3.3 Astronomy

3.3.1 Context, overview and strategic objectives

This review focuses on the statements and objectives relating to astronomy in the 1996 White Paper on S&T, the NRDS and the TYIP. In terms of the clarificatory and summative assessments, the review focuses specifically on the DST's 2015 *National Strategy for Multi-Wavelength Astronomy*, and the NRF's implementation plan as outlined in the agency's overarching strategy for 2015-2020.[30]

The importance of promoting astronomy as a field of scientific endeavour was already clearly stated in the 1996 White Paper on S&T. In reference to the two astronomy-related national facilities already in existence – the South African Astronomical Observatory (SAAO) and the Hartebeesthoek Radioastronomical Observatory (HartRAO) – the White Paper noted that these facilities "have sound research records and are able to take advantage of the desire of northern hemisphere researchers to access quality data from the southern skies" (DACST, 1996: 45).

The NRDS identified astronomy as one of the basic science areas in which we had an "obvious geographic advantage" insofar as we had "good access to the Southern skies and the engineering capability to build telescopes locally" (DST, 2002: 52).

In 2007, legislation in the form of the Astronomy Geographic Advantage Act No. 21 of 2007 was introduced, the purpose of which is described in its preamble as: "To provide for the preservation and protection of areas within the Republic that are uniquely suited for optical and radio astronomy; to provide for intergovernmental co-operation and public consultation on matters concerning nationally significant astronomy advantage areas; and to provide for matters connected therewith."

In the TYIP, astronomy was subsumed under the Space Science and Technology grand challenge. The plan noted that South Africa had "already taken notable steps forward in this area, including building the Southern African Large Telescope" and was bidding to host the Square Kilometre Array large radio telescope (DST, 2008: 14). It also referenced the DST's Astronomy Geographical Advantage Programme, which aimed "to use the excellent viewing conditions on the subcontinent, and the depth of engineering and scientific talent available locally, to attract international astronomy projects" (ibid.).

In 2009, the NRF commissioned *A Position Paper on a Decadal Strategy for Human Capacity Development in Astronomy and Astrophysics in South Africa*, which was subsequently updated and amended by the Astronomy Working Group.[31] In 2010, the Minister of S&T established the Astronomy Desk within the DST which would be tasked with advising the Minister and the Department on matters relating to a governance model for the management of astronomy in South Africa; the development of a long-term strategic plan for multi-wave length astronomy in South Africa; and human capacity development in astronomy. In 2013, the NRF appointed its inaugural Astronomy Advisory Council to oversee and advise the NRF's Astronomy sub-Agency.

In 2015, the DST published the *National Strategy for Multi-Wavelength Astronomy*. The strategy noted that the implementation plan for the strategy would be developed by the NRF and its Astronomy Sub-agency. The overarching mission and strategic objectives of the strategy are presented in the table below.

Multi-Wavelength Astronomy strategic objectives

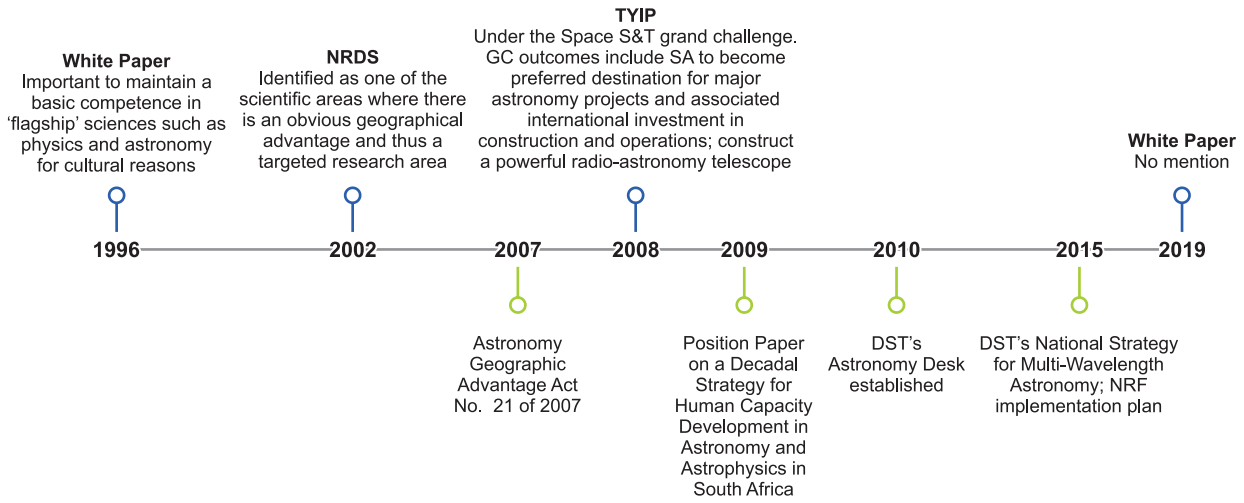
Mission	Develop astronomy as a means to stimulate frontier science, cutting-edge technology and human capacity development within South Africa and throughout the African continent	
Strategic objectives	1	To promote South African astronomy research and development to be globally competitive
	2	To support human capital development that is representative of the national demographics and that develops world-class scientific, engineering and technical skills
	3	To support the strengthening and expansion of appropriate astronomy infrastructure that is both world-class and scientifically productive

[30] NRF. 2015. National Research Foundation Strategy 2020. Pretoria: National Research Foundation.
[31] Bharuth-Ram K. 2011. Position Paper on a Decadal Strategy for Human Capacity Development in Astronomy and Astrophysics in South Africa. Pretoria: National Research Foundation. Available at: https://www.nrf.ac.za/sites/default/files/documents/Astro_Report_HCD_AWGupdated.pdf.

	4	To establish a governance framework to coordinate and integrate astronomy activities
	5	To ensure that the advantages of astronomy, such as Big Data and the transfer of skills, are translated into socio-economic benefits for South Africa
	6	To promote outreach activities in support of public awareness and education

The key national-level developments relating to astronomy are depicted in the figure below.

National-level timeline of key developments relating to astronomy



3.3.2 Assessments

Our assessment of the strategy design is provided in the table below.

Well addressed

Moderately well addressed

Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy/plan?		Yes. The motivation for investment in astronomy in the NRDS is based on a mixture of historic continuity and the exploitation of evident southern geographic advantage. The Multi-Wavelength Astronomy Strategy continues this focus but adds that there is a need to further develop current strengths in the field, have a coordinated strategy to maximise return on the considerable investments already made, and address the various challenges outlined in the 2009 Decadal Strategy for Human Capital Development in Astronomy and Astrophysics.
Are the goals and objectives clear and unambiguously formulated?		The overarching goal/mission of the strategy is clearly formulated. The strategic objectives of the strategy are well and clearly formulated and do appear to sum to the expected outcomes of the overarching goal. The same can be said of the strategic objectives listed in the NRF Strategy 2020 relating to astronomy.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		The strategy's eight "programmatic interventions" do not have associated activities, but rather quite detailed "key success factors" from which activities can be derived. While they are specific, they are articulated at a high level and not formulated in measurable terms. However, the "critical implementation activities" listed in the NRF Strategy 2020 are specific and, since they have detailed indicators attached, are also measurable.

		A range of role-players are mentioned throughout the strategy but these are not systematically linked to the interventions or activities.
Is a budget for the interventions provided?		No budget is provided in the strategy. Multi-wavelength Astronomy is one of the NRF's Knowledge Fields Development instruments. The NRF's Annual Performance Plan 2015/16-2017/18 provides budget estimates for astronomy and SKA up until 2018.
Are targets and milestones included?		No targets are set in the Multi-wavelength Astronomy Strategy. However, specific targets are set in the NRF Strategy 2020. No milestones specified.
Are intervention outputs clearly specified?		Not clearly specified in the strategy. However, again, these are much more explicit in the NRF Strategy 2020 in the form of strategy indicators.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		Although not demarcated as such, the expected outcomes of the Multi-wavelength Astronomy Strategy can be deduced from both the descriptions of the strategic objectives and the key success factors linked to the programmatic interventions. By contrast, the NRF Strategy 2020 lists specific "strategic outcomes" (although these relate to the NRF's activities as a whole and not just to astronomy).
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		Indicators are specified in the NRF Strategy 2020 which are concrete and measurable.

In the table below we broadly assess the achievements/progress made towards implementation of the astronomy strategic objectives of the NRF Strategy 2020.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of performance against the NRF Annual Performance Plan 2018/19 astronomy targets[32]

Strategic objective	Indicator	Target 2018/19	Actual 2018/19	Comment[33]	
Promote globally competitive research and innovation	No. of postgraduate students supported by the national research facilities	125	97	*A redefinition of the performance descriptor during the financial year resulted in lower numbers being reported. Planning for the 2019/20 financial year was performed in accordance with the redefined descriptor.*	
	ISI (WoS) publications produced by staff at national research facilities	142	210	*Excellent performance from both facilities reflects the impact of research infrastructure renewal over the past few years.*	
	No. of users of national research facilities	1,370	1,327	*Infrastructure renewal at the facilities attracted demand for utilisation across the research community.*	
	Citation impact of national research facilities outputs (annual cumulative)	>1.32	1.54	*Papers published have a higher impact within the community and citation has, therefore, increased.*	

Strategic objective	Indicator	Target 2018/19	Actual 2018/19	Comment[33]	
Enhance strategic international engagements	No. of joint international agreements at national research facilities	45	31	A redefinition of the performance descriptor during the financial year resulted in lower numbers being reported. Planning for the 2019/20 financial year was performed in accordance with the redefined descriptor.	
Establish and maintain research infrastructure and platforms	Total infrastructure investment in national research facilities (Rm)	315.17	200.00	Slower than anticipated progress during the pre-construction phase relative to SKA I and MeerKAT additional features.	

Source: NRF (2019: 49-51)

It is reasonable to claim that DST has been successful in engaging with Big Science, in promoting 'flagship science,' and in establishing new institutions such as SARAO. The earlier claims of the National Strategy for Multi-Wavelength Astronomy (2015) have been largely achieved. The commissioning of the MeerKAT facility is an important milestone in progress toward building the SKA.

South African astronomy, evaluated against its own objectives, and the embedded objectives of the three post-1994 policy instruments, has made impressive gains. Arguably, astronomy is **the** success story for the research and innovation system.

The actual benefit accruing to local communities is more difficult to establish,[34] the more so as the SKA (mid- and high-frequency array) has yet to be constructed, and much astronomy research is conducted remotely rather than primarily using local infrastructure. We therefore recommend that a systematic evaluation be undertaken of the extent to which the investment in astronomy has produced the expected societal and development outcomes.

The achievements in astronomy speak to the importance of the role of project champions in the political, scientific, technical and administrative dimensions.

On the downside, the question must be posed whether further large support for blue sky research is justifiable in a country with the triple burden of poverty, unemployment, and high inequality. It is all very well to 'reach for the stars,' but socio-economic returns are a distant prospect, the more so with the global economy that is in recession. The rules of the game make the prospect of massive domestic procurement for the SKA unlikely.

3.4 Palaeosciences

3.4.1 Context, overview and strategic goals

In the NRDS, human palaeontology was identified as a scientific research area in which South Africa has an "obvious geographical advantage" (DST, 2002: 52). The TYIP makes little explicit reference to the palaeosciences but, consistent with the text in the NRDS, considered palaeontology as an important scientific research area. Under the Human and Social Dynamics grand challenge, the TYIP advocates research in areas which include palaeoanthropology, archaeology and evolution genetics (DST, 2008: 20). Under this grand challenge, the TYIP considers such research to provide evidence-based support for interventions in learning processes and education, indigenous knowledge systems and heritage legacy.

In 2011, the DST developed the draft *South African Strategy for the Palaeosciences*. The DST started implementing the strategy under the African Origins Platform (AOP) in 2012. However, the strategy was only formally launched in 2013 with the establishment of the Palaeosciences Centre of Excellence at the University

[32] Note that in the reporting of performance against strategic objectives in the NRF annual report for 2018/19, figures are given for targets in the NRF Strategy 2020 as well as the revised targets as set out in the NRF Annual Performance Plan for 2018/19. The figures in this table are based on the latter.
[33] Direct quotations italicised.
[34] See e.g. http://repository.hsrc.ac.za/bitstream/handle/20.500.11910/11277/10033.pdf?sequence=1

of Witwatersrand. In 2014, the *South African Strategy for the Palaeosciences: DST Implementation Plan, 2014-2020* was published.

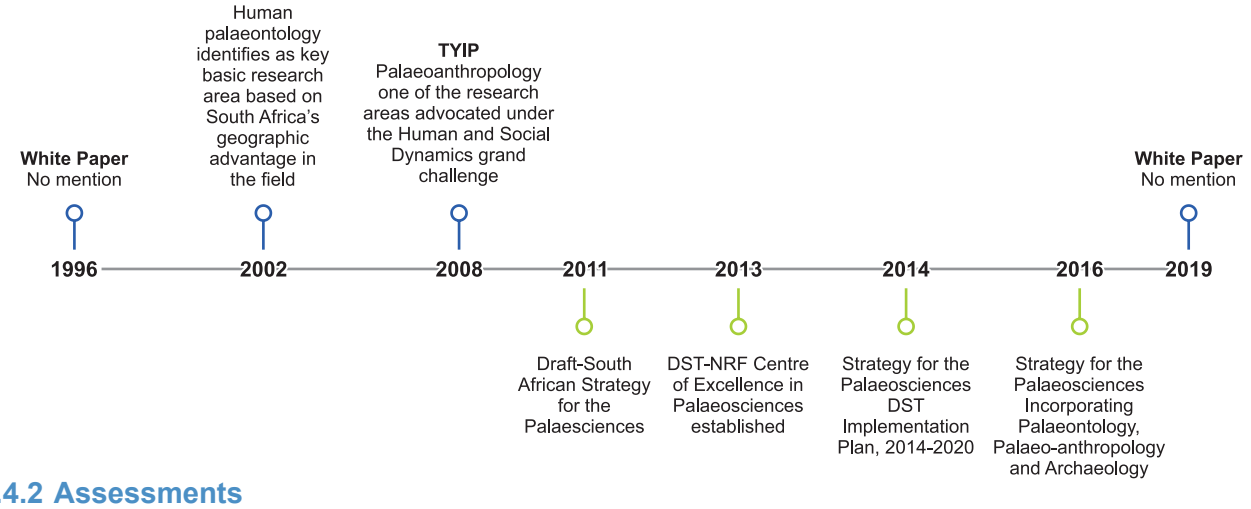
This was followed in 2016 by the *South African Strategy for the Palaeosciences: Incorporating Palaeontology, Palaeo-anthropology and Archaeology*, which we understand to be the final version of the 2011 draft. The 2016 Palaeosciences Strategy has five main goal statements. Linked to each of these are both short-term interventions and medium-term strategic targets, as articulated in the 2014 implementation plan. The main goal statements, as outlined in the strategy document, are presented in the table below.

Strategic goals of the Palaeosciences Strategy

Aim	This strategy is intended to provide a holistic framework for the development of palaeosciences	
Strategic goals	1	Transform the minds of South Africans so as to instil a sense of pride and provide the intellectual content to their African heritage so as to make them informed and responsible citizens, and to engage all sectors of society in palaeoscience matters, through information on discoveries that will allow them to appreciate the special place of South Africa in the story of life and humanity on Earth
	2	Support the country's universities to produce a critical mass of palaeoscience researchers with a range of research, technical, curatorial, public engagement and managerial skills and drive knowledge production and exploitation to make South Africa a world centre of scientific excellence in the palaeosciences
	3	Enhance the capacity of museums to curate, conduct and support research in palaeosciences in ways that inform South Africans and the world
	4	Ensure that South Africa's palaeoscience heritage is well managed so as to attain international standards of heritage management and ensure that the country's palaeoscience heritage is well managed and used for the benefit of current and future generations
	5	Make South Africa the destination of choice for palaeo-tourism by building a network of site displays and interpretative centres which are managed in a socially responsible and sustainable manner

The key developments relating to the palaeosciences[35] are depicted in the figure below.

Timeline of key developments relating to the palaeosciences



3.4.2 Assessments

Our assessment of the strategy and implementation design is provided in the table below.

Well addressed

Moderately well addressed

Poorly addressed or not addressed at all

[35] The palaeosciences refer collectively to the scientific fields of palaeontology, palaeoanthropology, archaeology and related disciplines

Assessment of strategy and implementation plan design

Is any reference made to problems or challenges being addressed by the strategy/plan?		Not explicitly, but reference is made to limited human capacity within the palaeosciences.
Are the goals and objectives clear and unambiguously formulated?		The strategy's five goal statements are reasonably well-formulated. These are further clarified by the sub-goals and indicator-linked statements.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		The activities, in most cases, are clearly specified in the implementation plan with clear indication of the responsible agency.
Is a budget for the interventions provided?		A dedicated budget is attached to the strategy.
Are targets and milestones included?		Some targets and milestones (delivery dates) are specified, but not in all cases.
Are intervention outputs clearly specified?		Yes, in most cases.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		No, this is the biggest deficiency in the strategy and implementation plan. Although the strategy distinguishes between short- and medium-term interventions, the focus is mostly on outputs rather than outcomes. Key outcome statements related to "strengthened HR capacity", "increased awareness", "world-class palaeosciences", "and effective heritage resource management" are left undefined.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		There are no outcome indicators in any of the tables.

Assessment of the implementation of the interventions and associated activities for each strategic goal is provided below.

- Achieved
- Partially achieved
- Not achieved at all
- Not possible to make a judgement

Assessment of implementation of the Palaeosciences Strategy

Strategic goals	Interventions and activities		Comments
Transform the minds of South Africans	Develop travelling exhibitions on origins of life on earth for schools (science centres through SAASTA)[36]		In 2019, the Origins of Early Sapiens Behaviour exhibition was launched by the CoE. The CoE puts on exhibits at various centres every year. SAASTA has not developed any exhibits and thus the assessment of 'partially achieved'.
	Improve public awareness and appreciation of palaeosciences culture and heritage within local communities (coordinated by SAASTA)		The CoE organises outreach activities aimed mainly at school learners which include the SAASTA National Science Week. However, no evidence of activities undertaken by SAASTA itself.
	Improve the accessibility of museums and palaeosciences sites (COH WHS MA[37] and DAC[38])		In 2018, Cabinet approved the Policy Framework on National Museums, which aims to transform the management and operations of museums in terms of access, redress, equity, nation-building and social cohesion. However, no evidence that the policy framework has improved the accessibility of sites and further investigation is needed to assess this intervention.
	Strengthen science awareness programmes managed by SAASTA that target school learners		The CoE has launched science awareness programmes. A review of the evidence revealed that SAASTA has not taken the lead on this intervention – hence assessment of 'partial achievement'.
	Develop user-friendly, informative products for use by pupils (SAASTA and DBE[39])		Some palaeosciences learner materials have been developed but not produced regularly.
	A travelling exhibition to be linked to DST premier awareness programmes and showcased at events associated with such programmes		The CoE has put on exhibits at different venues in the country but reports that these are not travelling exhibitions. In 2015 the DST reported that two travelling exhibitions had been produced.
	The NRF AOP support initiative to be utilised as the core programme from which community projects are targeted		The AOP funding programme has continuously supported postgraduate students in palaeosciences. However, in order to assess whether it acts as a core programme for community projects, further evidence is needed.
	The DST and DBE to work in concert with universities and teachers in developing appropriate pre-service and continuous development for science teachers		Current evidence does not reveal whether there have been efforts to enable the development of science teachers.
Support the country's universities	Support the development of heritage skills through undergraduate bursary programmes		The implementation plan reported that DAC was (at the time) running an undergraduate support programme for heritage sciences of which palaeosciences disciplines are the core. The first cohort of beneficiaries started in 2012. The programme continued into the current 2013/14 MTEF.

[36] South African Agency for Science and Technology Advancement.
[37] Cradle of Humankind World Heritage Site Management Authority.
[38] Department of Arts and Culture.
[39] Department of Basic Education.

Strategic goals	Interventions and activities		Comments
	Develop a focussed postgraduate bursary programme for the palaeosciences		• According to the implementation plan, postgraduates are catered for through the AOP grant-holder linked bursary programme. It was anticipated that a new AOP bursary programme would be established in 2014 under the NRF. Evidence shows that the AOP funding instrument continued to support students at least until 2018 (latest year for which we have data). • The plan also states that the DAC (in 2014) offered grants for postgraduates requiring in-service training. However, our review found no evidence that DAC is offering financial support, through bursary programmes, to postgraduates. • In 2015, the DST reported that bursary support for postgraduates and postdoctoral fellows included 29 bursaries in 2009/10 which increased to 60 in 2015. However, they did not state the source of the bursaries. • Since its inception to 2018, the CoE reported that it had supported 34 postgraduate students.
	Develop a postgraduate development programme		• The implementation plan stated that at the time of writing the Plan the NRF called for proposals which invited applications for PDPs (which support masters and doctoral students at entry-level employment). • The AOP also supports a developmental programme (Early Career Researchers) for entry-level researchers with the aim of incorporating them into mainstream research. The implementation plan anticipated that both programmes would continue in the 2013/14 MTEF. • While we have evidence that the AOP programme has continued, we cannot make an assessment of whether this programme includes developmental programme for Early Career researchers. • Expert feedback revealed that these programmes were to be implemented in 2018, but we need further evidence in support of their implementation. Postgraduate students are, however, supported through the CoE.
	Develop an internship programme		• The implementation plan reported that in 2011 the DST introduced a palaeosciences category within the DST/NRF broad internship programme. This programme continues into the MTEF.
			• In 2017/18, 16 interns attended the CoE fossil discovery media briefing as part of the Job Shadowing Programme.
			One of the planned activities included DAC to consult with the National Learner Records Database and create a register of unemployed graduates to facilitate placement in internships and apprenticeship programmes. We could not find evidence that progress towards this activity has been made and whether such a database has been constructed.

Strategic goals	Interventions and activities		Comments
	Develop skills required to support palaeosciences		The implementation plan called for the DST to engage with DHET to encourage the relevant SETAs to assist in the development of technical skills in the field. In 2015, the DST reported that in 2011/12 it had initiated the Technical Skills Programme, which was fully subscribed in 2015. However, expert feedback considers the programme as not sufficient in providing support for capacity building in the palaeosciences.
			The implementation plan called on DAC to develop a grant system for heritage practitioners who only need in-service training on specific skills. However, we found no evidence that DAC has in fact developed or is developing such a grant system. The CoE offers training opportunities to people at various levels of the job market and other related fields in palaeo-tourism. We therefore consider this intervention to be partially achieved as the activities are led by the CoE and not DAC.
	Support research infrastructure through the National Equipment Programme (NEP)		The implementation plan reported that the NRF had made available funds to acquire the Micro CT scanner through the NEP. Additionally, the palaeosciences equipment programme has been developed to assist with small research equipment needs. This is linked to the NRF AOP grant call. The DST reported that in 2012 it supported the installation of a Microfocus X-ray Computed Tomography (CT) Scanner at Wits. In 2013, the DST funded the installation of Africa's first Accelerator Mass Spectrometry (AMS) at the iThemba labs.
	Establish at least one national research centre of excellence		The Palaeosciences CoE was established in April 2013.
	Establish centralised scientific laboratories		The implementation plan called for a framework to be developed to identify how the existing infrastructure could be accessed to benefit the broader South African and African community. We found no evidence that such a framework has been developed and thus need further evidence in order to make an assessment.
	Strengthen collaborations with institutions in China; initiate collaborations with countries in Africa		The implementation plan reported that engagements with Tanzania and China have been initiated on possible collaboration and that at the time (2014) a formal collaboration had been established with China.
	Strengthen diminishing areas and ensure that existing areas are maintained		Through the implementation plan and strategy, research chairs in palaeosciences have been prioritised and the CoE call ensured that these diminishing areas are addressed. The plan called for a special category for critical and diminishing research areas to be allocated for the 2014/15 NRF AOP research call and in future years. Subsequently, two of the three research chairs have been established.
Enhance the capacity of museums	Attract and retain scarce skills		The implementation plan stated that (at the time) the NRF provided museums with grants to attract fossil preparators and associated technical requirements. Additionally, the DST/NRF Internship programme provided access to internship placement, and museums were accessing the DST/NRF professional development grants. DAC currently provides support, through grants, for skills development.

Strategic goals	Interventions and activities		Comments
	Support the curation of collections		The NRF has made an allocation of R5 million to support curation of collections within national museums. Expert feedback revealed that these allocations, however, are aimed towards all Natural History Collections and not specifically for the palaeosciences.
	Improve staff conditions of service		The implementation plan mentions that talent retention schemes such as equitable remuneration, reward, recognition and benefits would be offered, and that Occupation Specific Dispensation was to be considered by DAC for research positions in museums. However, we found no reference to these schemes in the documents reviewed. We are thus not able to make an assessment towards progress of this intervention.
	Create, in the medium term, 21 new entry-level research contract positions for the seven museums in the country		In 2015, the DST reported that at the time no research posts for museums had been developed and thus progress towards this intervention had not been achieved. We found no evidence that these positions have or have not been established since then and are therefore unable to assess this intervention.
	Allocate a minimum amount of R36 million towards improvement of museum infrastructure to at least three regions of the country		The NRF has made funds available to museums to improve infrastructure. The DST (2015) reported that the DST/NRF provided a once-off funding allocation for natural science museums to improve their research equipment. However, we do not know the value of funds allocated. The Iziko, National and Ditsong Museums were successful in their applications. Currently, Iziko Museum is revamping their collection space, and collections have been hard to access. We therefore assess this intervention as partially achieved.
	DAC to provide support for museum officials requiring in-service training		• We have not found evidence that DAC has made progress towards this intervention. However, the CoE offers training opportunities at various levels of the job market (academic, heritage practitioners, museum curators/collection managers, etc.) and other related fields in palaeo-tourism. • The draft museum policy calls for an occupational framework that details training standards for the museum sector. However, given the lack of evidence found, we cannot assess progress towards this intervention.
	DAC, though its current bursary programme, to develop a programme geared towards provision of formal training to museum staff with no formal training		In our review of relevant documents, we have not found evidence regarding whether DAC is providing support to museum staff through its bursary programme, and are thus unable to make an assessment of this intervention.
	Universities, museums and science councils engaging in palaeosciences to have specialist regional network centres anchored by existing skill sets; to be piloted in the short term through the CoE		The CoE offers training opportunities at various levels of the job market (academic, heritage practitioners, museum curators/collection managers, etc.) and other related fields in palaeo-tourism. We rate this intervention partially achieved as this activity is currently only driven through the CoE.

Strategic goals	Interventions and activities		Comments
	The implementation of the Heritage Human Resource Development Strategy (HHRDS), developed by DAC, to address the remuneration of museum staff as a priority		In our review of the evidence and the HHRDS, we found no reference that the remuneration of museum staff is being addressed. We need further evidence so assess progress towards this intervention.
	DAC, through SAHRA,[40] to consolidate the existing databases of heritage collections in the country; audit for palaeosciences heritage to be initiated		The management of the inventory of the national estate is a key focus area for SAHRA and will continue to actively seek opportunities to expand the database of heritage resources. However, the National Science Collections Facility, and not DAC, has driven this intervention.
	DAC to develop a national policy on minimum standards for curation of collections and protocols on accessing collections		Curatorial efficiency has been increased by the development of a Pan-African curatorial network through the CoE. However, the National Science Collections Facility, and not DAC, has driven this intervention.
Ensure that South Africa's palaeosciences heritage is well managed	Joint review of heritage management framework		According to the CoE Self-Assessment report (DST/NRF 2018): "A feature of the CoE-Palaeo is the number of partner institutions, particularly museums that form a valuable formal network of researchers in the palaeosciences. The Centre has an extensive network of collaborations both abroad and locally which is encouraged to expand. Attention is given to supporting researchers on the African continent to engage in collaborative programmes with the CoE-Palaeo." However, there is no evidence that this review has been conducted.
			The Palaeosciences Strategy noted the need to develop a Joint Steering Committee on the review of heritage legislation. We have not been able to find evidence that such a committee has been established.
	DAC to develop a national policy on the digitisation of heritage resources		"The DAC has developed a national policy on the digitisation of heritage resources to ensure sustainability of heritage resources to ensure accessibility of heritage resources. However, the draft policy was developed in 2011 and is already considered outdated due to the rapid development of technology. The DAC is therefore in the process of updating and revising the draft policy. Consultation on the reviewed policy will be done in the 2018/19 financial year, followed by processes to ultimately submit the reviewed Policy to Cabinet for approval."

[40] South African Heritage Resources Authority.

Strategic goals	Interventions and activities		Comments
	A comprehensive heritage legislation review report to be developed (2015/16 MTEF)		A review of heritage legislation was done by the DAC in 2014. However, our external reviewer pointed out that "the heritage legislation of this country does not effectively manage palaeoscience resources. The Palaeontological Community was never consulted when the legislation was drafted, and the Palaeontological community has petitioned SAHRA and the minister to get this rectified, but they are in fact doing the reverse. The legislation must change as it does not work. Or amendments to the existing legislation must be accepted and implemented." Although a review of the legislation was therefore conducted, the legislation has not managed been effective in its mandate.
	DAC and DST to explore the inclusion of heritage resource agencies and museums onto the SANRe[41]		In 2015, the DST reported that at the time no museums and heritage agencies had broadband connectivity through SANReN and they considered progress towards this intervention as not achieved.
	DST and SAHRA to lead process of making heritage resource collections digitally accessible to all museums and collections repositories		We found no evidence that DST and SAHRA have made progress towards facilitating digital access of heritage resources. In order to make an assessment of this intervention, further evidence is needed.
Make South Africa a destination of choice for palaeo-tourism	Review the current model for the management and governance of heritage tourism		The implementation plan states that the NDT[42] has developed a framework (the National Heritage and Cultural Tourism Strategy) which provides strategic focus on the development of heritage tourism in South Africa. This framework responds to the need to integrate cultural and heritage tourism to mainstream tourism.
	Develop heritage tourism routes which link common palaeosciences sites		The implementation plan and strategy state that to effectively market heritage tourism, a number of heritage sites need to be developed as part of tourism routes. The plan called for the DAC, NDT and GTA to coordinate the process for development of tourism routes. Our evidence shows that to date only one centre to promote palaeo-tourism has been established. The Kitching Fossil Exploration Centre was established and acts as a model of self-sustaining palaeo-tourism ventures in rural parts to enhance palaeo-tourism. However, we found little evidence in support of heritage tourism routes.
	Profile South Africa as a palaeosciences destination		In our review of the evidence documents, very little or no reference is made to palaeo-tourism in the strategic frameworks of the NDT. Incremental progress towards these interventions has been made by the CoE and its network. But we need further evidence to assess progress towards interventions aimed at expanding palaeo-tourism in South Africa.
	NDT, supported by the DST, to lead and initiate consultations with COH WHS MA to access and model a tourism plan for the development of a similar arrangement for other palaeo-heritage sites		
	New sites to be assessed for tourism potential and suitable sites included in the heritage tourism route		

[41] South African National Research Network.
[42] National Department of Tourism.

The Palaeosciences Strategy is an integrated strategy aimed at promoting the palaeosciences in South Africa. Although the objectives of the strategy are reasonably well-formulated, some statements about expected outcomes are broad and not necessarily measurable. Our assessment of the progress of implementation of the strategy is generally, positive. However, a comprehensive outcome or impact evolution of the strategy can only be made in 2021/22 as the timeframe for the implementation of the majority of the strategy's goals/targets are planned for completion by March 2021.

Nevertheless, there is sufficient evidence that good progress has been made towards the achievement of the first two goals with much of this progress due to work done by the Centre of Excellence in Palaeosciences at Wits University. Limiting evidence was found to make an accurate assessment of progress towards goals four and five which pertain to palaeo-tourism and South Africa's palaeosciences heritage. Proposed interventions and outcomes where clear ownership is assigned appear to have a greater likelihood of being implemented successfully. From our assessment, the CoE has proven successful in driving research and building human capacity in the palaeosciences, but state entities (such as the DAC, NDT and SAHRA) have been less effective in their efforts to promote palaeo-tourism and palaeosciences heritage. However, the strategy offers very few measurable (quantitative) targets which makes a detailed assessment of progress more difficult.

This review has highlighted that most of the progress of the Palaeosciences Strategy would not have taken place without the intervention of the CoE in Palaeosciences. The CoE has been very successful in meeting its diverse targets and is especially productive in research output, providing bursaries and training for postgraduate students, and for its very extensive outreach and science communication programme.

The CoE in Palaeosciences is the only CoE in South Africa which has Natural History Museums as partners, largely because these museums curate the palaeoscience collections on behalf of the country. Museums also have the mandate to undertake research using the collections, but the Natural History Museums (which largely fall under the direction of DAC) are not coming up to their full potential as far as research is concerned. Conversely the University of the Witwatersrand and University of Cape Town have been extraordinarily productive in both research output and the training and graduation of postgraduate students in the palaeosciences. However, recently, there has been low research output from museums, and a clear lack of interest in museum management in understanding the significance of research to their collections and for the development of relevant exhibits which will attract public attention.

3.5 Marine and Antarctic sciences

3.5.1 Context, overview and strategic goals

In 2002, 'Antarctic, Islands and Oceans' was one of five science focus areas identified in the NRDS for long-term action. In 2003, Cabinet approved the transfer of the scientific research functions of the already established South African National Antarctic Programme (SANAP) from the then Department of Environmental Affairs and Tourism (DEAT) to the DST, with the NRF becoming the agency responsible for grant-making on behalf of the Department. In 2005, the DST drafted the *Antarctic Research Strategy for South Africa* (ARESSA), the main elements of which are outlined in section 2.2 below.

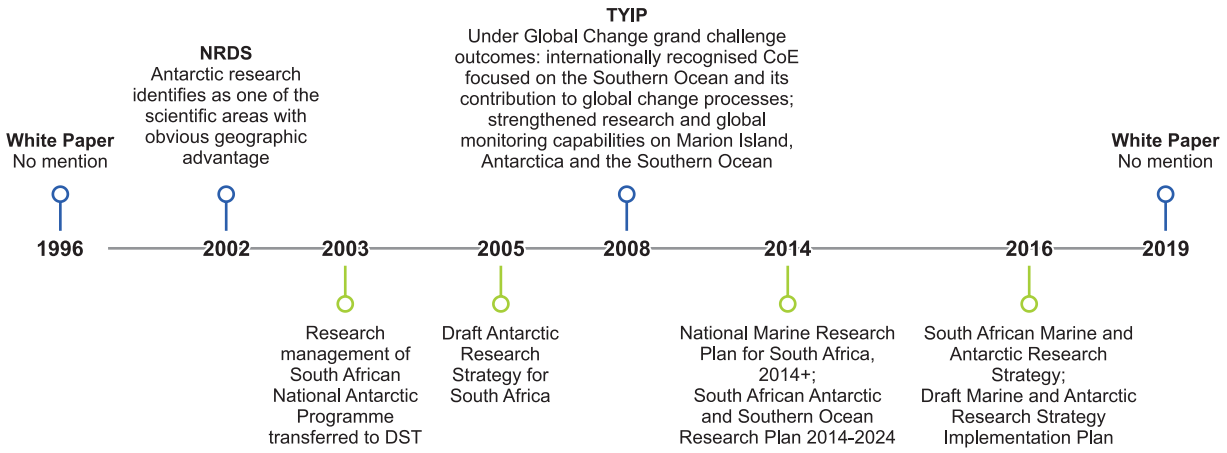
The 2008 TYIP continued the NRDS focus on this field of scientific research, referring to 'Antarctic, Southern Ocean and marine science' as part of its Global Change Grand Challenge (GCGC). In 2011, the DST started work on a new Antarctic strategy and research plan, but this was never approved. In 2014, the DST's *National Marine Research Plan for South Africa, 2014+* and the *NRF's South African Antarctic and Southern Ocean Research Plan 2014–2024* were published. Also in 2014, and as part of the implementation of the National Development Plan, Operation Phakisa: Ocean Economy was launched "whose key purpose is to maximise the socio-economic return accruing from South Africa's proximity to massive ocean resources" (DST/DEA, 2016: 2).[44]

The focus of this review is on the *South African Marine and Antarctic Research Strategy* published by the DST and the Department of Environmental Affairs (DEA) in 2016, and its associated draft implementation plan prepared by the DST.

[44] DST/DEA. 2016. *South African Marine and Antarctic Research Strategy.* Version 4.5, June 2016. Pretoria: Department of Science and Technology and Department of Environmental Affairs. Seven SARChI chairs in related sciences have been established since 2007.

The key developments relating to the Antarctic and marine sciences are depicted in the figure below. Over the past two decades, considerable investments have been made in infrastructure, equipment and state-of-the-art platforms, as well as in research and human capacity development.

Timeline of key developments relating to the marine and antarctic sciences



A major purpose of the 2016 Marine and Antarctic Research Strategy (MARS) is "to provide an over-arching policy framework for a wide range of pre-existing programme and project-level plans, policies and strategies" (DST/DEA, 2016: 8). As such, the strategy constitutes a codification of existing research programmes and activities, and is intended to align all national research needs (of various government departments, relevant to their specific administrative and regulatory mandates) in the marine and antarctic domains.

The MARS is constructed around six strategic, high-level objectives which are outlined below.

Strategic objectives of the Marine and Antarctic Research Strategy

Mission	To build the national marine and antarctic research system in order to develop human capital; maximise South Africa's international profile for research in this domain; bring about transformation in the sector; and contribute to innovation and economic growth around the oceans economy	
Strategic objectives	1	Provision of a well-coordinated governance system for marine and antarctic research activities
	2	Ensuring sustainability of marine and antarctic resources
	3	Development of high-level skills to support research and development in the marine and antarctic domains
	4	Improving the quality of life for South Africans derived from the oceans economy
	5	Creation of a society informed on the value of marine and antarctic research initiatives
	6	Contribute towards the creation of employment derived from innovation in the marine and antarctic environments

[45] For example, the African Coelacanth Ecosystem Programme (which has subsequently morphed into several platforms that also include infrastructure); the Southern Ocean Carbon and Climate Observatory (SOCCO); the Agulhas System Climate Array established within the South African Environmenta Observation Network (SAEON); research bases on Gough Island, Marion Island and SANAE IV (Vesleskarvet, Queen Maud Land); the polar research and supply vessel, the SA Agulhas II; and a new ocean robotics facility at the CSIR as part of SOCCO.

[46] Seven SARChI chairs in related sciences have been established since 2007.

The MARS identified six cross-cutting "support interventions as modalities of implementing the delivery of the strategy" (DST, 2016: 5).[47] These include:

- Coordination and governance
- Human capital development and transformation
- Research capacity development
- Public awareness and engagement
- Infrastructure and research platforms
- Data management.

While little in the way of specific activities associated with these interventions are highlighted in the MARS, they are elaborated on in detail in the draft implementation plan.

3.5.2 Assessments

Our assessment of the strategy and implementation design is provided in the table below.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of strategy and implementation plan design

Is any reference made to problems or challenges being addressed by the strategy/plan?		Yes, primarily the lack of coordination in oceans, antarctic and climate change research (including the definition of strategic priorities across several key stakeholders, and aligning research and logistics, particularly for antarctic-related research). It is also explicitly stated that MARS needs to: respond to a wide range of challenges (strategic and operational), which include the need to: promote fundamental and applied research in order to increase human knowledge and develop multidisciplinary links between basic and applied research and knowledge; develop the necessary human capital base aligned with national plans and instruments; breed innovation and links to relevant industry to exploit commercial opportunities; and grow general public awareness and engagement that is aligned with national plans and instruments.
Are the goals and objectives clear and unambiguously formulated?		The vision of MARS is clear and unambiguously formulated. However, MARS also contains a number of other overarching purpose and goal statements. The six strategic, high-level objectives are clear and well-formulated.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		Six cross-cutting interventions are identified as critical to delivering on MARS. In the strategy document, associated activities are only vaguely referenced. However, the implementation plan provides extensive detail about activities associated with each intervention, most of which are specific, but not necessarily measurable. There is a considerable level of detail in the implementation plan about who should be involved in carrying out the activities.
Is a budget for the interventions provided?		The MARS itself does not provide any indication of estimated budget for interventions. The implementation plan provides minimum estimated costs against a number of specific activities in its detailed tables.

[47] DST. 2016. Marine and Antarctic Research Strategy Implementation Plan. Draft 2.4 (development document). Pretoria: Department of Science and Technology.

Are targets and milestones included?		Targets are specified in the implementation plan, but the term is often used to refer to other concepts than quantities of outputs. Milestones are specified in the implementation plan, but the term is confused with targets.
Are intervention outputs clearly specified?		In the implementation plan, in the majority of cases, yes.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		Intervention outcomes are specified in some cases in the implementation plan, but not in clear, quantitative terms. In the case of most of the interventions, a distinction is made between short-term (or immediate) targets, medium-term targets, and long-term targets or goals. In the case of one intervention, the distinction is between two "time scales for actions" (short-term and medium-term or medium-to-long term).
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		In the implementation plan, some indicators are explicitly specified, but only with reference to Intervention 2 (Human Capital and Transformation and Research Capacity Development).

As the table above shows, the MARS and its associated implementation plan meet good practice in evaluation research with well-formulated goal and objective statements, the inclusion of outcomes and outcome indicators as well as targets and milestones. From a strategy design point of view, the MARS is well-put together and is clear about its strategic intents.

A summative assessment of the implementation of MARS was not conducted for this review, primarily because at the time of undertaking the review the implementation plan had not been formally approved by the Minister, and many of the targets in the plan extend beyond 2019.

We have been able to ascertain that from a governance and coordination point of view, a DST-DEA Marine and Antarctic Research Deputy Directors-General Forum was established in 2013 which, in 2016, the became the Marine and Antarctic Research Coordinating Committee (MARCC). The MARCC then established a more operational body in the form of the Marine and Antarctic Science and Logistics Committee (MASLC).

The research aspects of MARS are currently being implemented via the two associated research plans; namely, the National Marine Research Plan for South Africa, 2014+ and the South African Antarctic and Southern Ocean Research Plan 2014–2024. According to a DST official, new initiatives have been put in place which form part of the implementation of MARS (some of which also form part of the Operation Phakisa: Oceans Economy initiative). Such initiatives include the National Oceans and Coastal Information Management System in 2015; the SEAMester Programme, Shallow Marine and Coastal Research Infrastructure Initiative, and South African Marine Research Exploration Forum in 2016; and the South African Marine and Antarctic Facility which is in the process of being established.

As far as could be determined, no reviews of the various marine and a antarctic-related strategies and research plans have been conducted. However, the academic community has provided some insights in articles published in the South African Journal of Science. From these we can highlight that one challenge associated with implementation has related to a lack of coordination between the designated agencies in government.

A case in point is the ongoing criticism from scientists and scholars over a lengthy period of time of the availability of scientific time on the Agulhas II. One reason for the difficulty in securing ship time for scientific research appears to relate to reshuffling of the Cabinet in 2009 and responsibilities within government ministries, which, according to Treasure et al. (2013),[48] resulted in a mismatch between funding and supervising agencies. In particular, there was only limited DST involvement in decisions concerning the availability and accessibility of the state-of-the-art research platform for one of its main groups of end-users (i.e. researchers at academic institutions and science councils). Of further concern was the fact that the timing for approval of research proposals and the deadline for applying for ship time differed between academic institutions and science

[48] Treasure AM, Moloney CL, Bester MN, McQuaid CD, Findlay KP, Best PB, et al. 2013. South African research in the Southern Ocean: New opportunities but serious challenges. *South African Journal of Science*, 109(3/4).

council scientists, and government departments. This difference resulted in a split mandate in the management of Southern Ocean sciences. The misalignment in communication and purpose between the two government departments tasked with overseeing and supporting the use of the SA Agulhas II for South African science and logistics was having a negative impact on research. Consequently, DST's goal of increasing South Africa's contributions to Southern Ocean and climate change science was being compromised.

A few years later, Ansorge et al. (2017)[49] noted a similar issue; namely, that the implementation of the national research effort on Antarctica and the Southern Ocean remained "fragmented, with strategic priorities defined across several key stakeholders in a largely uncoordinated manner" (ibid: 5). They furthermore noted various logistical challenges, including that "the bulk of oceanographic research continues to be restricted to the three logistic relief operations, with only an additional 30 dedicated sea days available each year. For land-based research, the relief voyages provide a major limitation by their time-constrained access to Antarctica and the islands (logistical requirements dictate research access)" (ibid: 5). In addition, the "number of participants per voyage is also limited by space; large numbers of berths are reserved for logistical and maintenance personnel" (ibid.).

3.6 Indigenous knowledge systems

3.6.1 Context, overview and strategic objectives

This review centres on the DST's 2004 *Indigenous Knowledge Systems Policy*. There is no single strategy or implementation plan associated with this policy, primarily because the domains of indigenous knowledge systems (IKS) and indigenous knowledge (IK) are multi-faceted and diffuse. They intersect with and are part of a wide range of knowledge, technology and innovation domains (e.g. intellectual property, technology transfer, biotechnology, biological and genetic resources, food security, culture, heritage, education), and involve a cross-section of stakeholders and role-players spanning government,[50] communities,[51] schools and universities, museums, and the private sector.

Various activities relating to IK and IKS, both within and outside of government, were already underway prior to the publication of the IKS Policy. IK and IKS had been on the national policy agenda since the mid-1990s. Although not mentioned specifically in the 1996 White Paper on S&T, an audit of indigenous technologies was undertaken in 1997. Reference to IK and IKS is made repeatedly in the early DACST annual reports, particularly with regard to arts and culture, but also in relation to IK technologies and poverty reduction. During 2001, a DST/NRF IKS Focus Area Programme was established with ring-fenced funding from DACST; the process of drafting legislation to promote and protect IK was begun;[52] and the National Biotechnology Strategy, which had an IK focus, was published in 2001.

IK and IKS feature in 2002 NRDS as one of the basic science areas in which South Africa had an important natural or knowledge advantage. IK is also relatively central to the NRDS's discussion of intellectual property and S&T for poverty reduction. During 2002, and as part of its coordination of IKS activities function, the DST established an Inter-departmental Committee on IKS. IK and IKS are part of the Bio-economy grand challenge in the 2008 TYIP, specifically in relation to biotechnology and pharmaceuticals.

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[49] Ansorge IJ, Skelton P, Bekker A, De Bruyn PJN, Butterworth D, Cilliers P. et al. 2017. Exploring South Africa's southern frontier: A 20-year vision for polar research through the South African National Antarctic Programme. *South African Journal of Science,* 113(5/6).

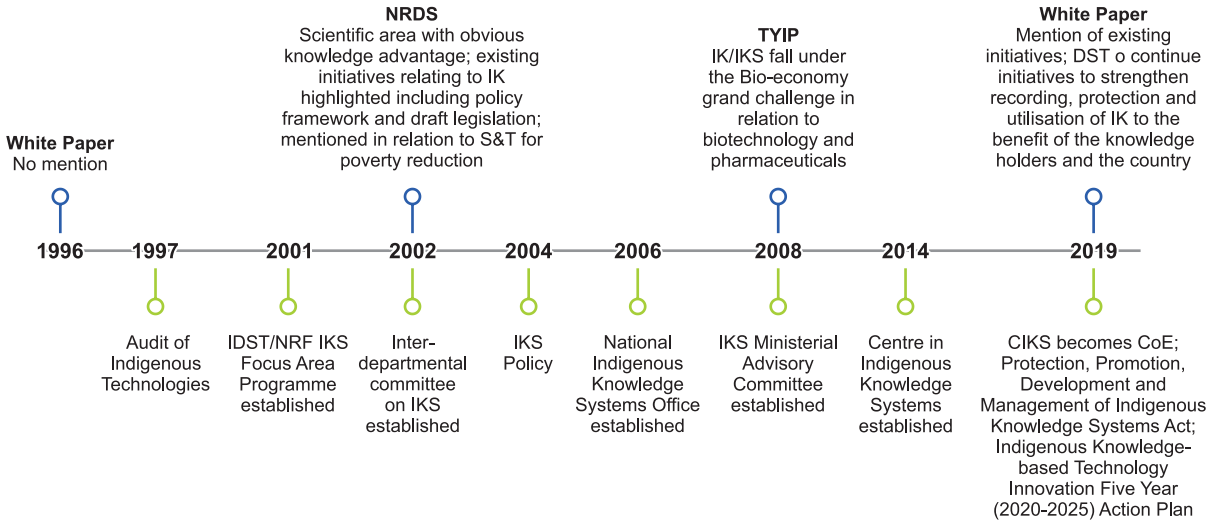
[50] Including departments relating to agriculture, arts and culture, S&T, education, environment and tourism, health, trade and industry, land affairs, water affairs and forestry, as well as provincial and local government.

[51] Including specific groupings such as traditional healers and women.

[52] Work on the draft legislation, as well as a draft IKS policy, was continued during 2002 by a national task team (DST Annual Report 2002/03).

Key developments relating to IK and IKS are captured in the figure below.

Timeline of key developments relating to IK and IKS



Since the object of this review is a policy and not a strategy, goals, interventions and associated activities are not particularly clearly formulated. Thus, the strategic objectives listed below have been reconstructed based on the drivers, functions and other themes discussed in the policy document, as well as the DST's briefing to the Portfolio Committee on S&T in 2016.[53]

Mission and strategic objectives of the IKS Policy

Mission	The IKS Policy is an enabling framework to stimulate and strengthen the contribution of indigenous knowledge to social and economic development in South Africa via the recognition, promotion, development, protection and affirmation of IKS	
Strategic objectives	1	Create an institutional framework for IKS
	2	Establish funding for IKS
	3	Develop administrative and legislative regulatory framework to support IKS
	4	Develop IKS human resource capacity
	5	Develop the information and research infrastructure for IKS

[53] *2004 IKS Policy: Role of Department of Science and Technology in policy implementation, and key achievements of the Department's IKS Programme.* Presentation to the Portfolio Committee on Science and Technology. Available at: http://pmg-assets.s3-website-eu-west-1.amazonaws.com/160817iks.pdf.

3.6.2 Assessments

Our assessment of the policy design in terms of a clarificatory evaluation does not include components relating to targets, indicators and outputs as these are not relevant to in the context of a policy document.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of policy design

Is any reference made to problems or challenges being addressed by the policy?		Yes, the policy mentions the "cultural implications of globalisation" as a challenge for the preservation of IK; the "individualistic nature of intellectual property regimes" complicating the legal protection of IK; and the lack of funding for IKS activities. Developing IKS is also a matter of redress: "Under apartheid, IKS in South Africa, as well as practitioners within such systems, were marginalized, suppressed and subjected to ridicule."
Are the goals and objectives clear and unambiguously formulated?		No, while the executive summary lists "functions" required for the implementation of this policy, they are vague, open for interpretation and not stated consistently through the document. Furthermore, it is difficult from the discussions in the policy to identify clear sub-goals and to distinguish suggestions from goals.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		No, very few of the identified interventions are clearly measurable. While the DST is responsible for coordinating the implementation of the policy, it is often unclear which agency or department is responsible for the implementation of an activity. This is partially because interventions are not easily identifiable.
Is a budget for the interventions provided?		No.

The summative assessment of the various interventions outlined in the IKS Policy is provided in the table below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation of the IKS Policy

Strategic objectives	Interventions	Activities		Comments
Create an institutional framework for IKS	Establish an Advisory Committee on IKS	Establish an Advisory Committee on IKS comprising representative stakeholders of interested institutions, communities, IKS holder and practitioners		IKS Ministerial Advisory Committee was established in 2008.
		• Specific activities assigned to the Committee: • Conduct enquiries, studies and consultations consistent with its expertise and composition initiated at the request of the government • Take steps to ensure that the subjects and terms of reference of its activities are made public • Be provided with a secretariat and a budget with which to commission relevant activities, including policy research in support of its programmes • Provide policy advice to the Minister of S&T • Establish a strong connection with NACI		Information regarding the implementation of these activities would require a separate evaluation of NIKSO.
	Create a National Office on IKS	A National Office on IKS be established within the DST		NIKSO was established in 2006 as well as through the IK Act of 2019.
		Provide public resources according to identified priorities		IKS Fund and NRF IKS programme established by NIKSO.
		Develop an implementation infrastructure for programmes related to these functions		Information regarding activities could not be obtained.
		Establish mechanisms for the nature and extent of relationships between IK holders and the research community, and the regulation of standards for information and material transfer agreements related to the IK		The NRF's 2018 *IKS Knowledge Advancement and Support Framework* describes nature of relationship between research community and IK holders. However, beyond this, it is unknown as to whether additional mechanisms have been put in place.
		Consider application for intent to access IK and IKS and conditions of fair and equitable benefit sharing		IK Act of 2019 described benefit sharing process.
		Maintain liaison with other Government Departments, foreign governments, IK holders in other countries, technical experts representing foreign agencies, and members of the public and private sector concerned with the protection of IKS		Information regarding activities could not be obtained.

Strategic objectives	Interventions	Activities		Comments
		Leverage funding to IKS laboratories and centres, and practitioners/holders for the purpose of R&D		NIKSO through the NRF Knowledge Fields Development Directorate created IKS funding programme in 2008.
		Maintain and disseminate information on IK		IKS information maintained through IKSDC[54] and disseminated through public awareness programmes. NIKSO's involvement not explicit, although it is a function of NIKSO as per IK Act.
		Advise indigenous/local communities/person on matters of dispute in collaboration with traditional leaders and other IKS stakeholders		Dispute process described in IK Act.
		Establish the extent of IKS, the identity of IK holders and forms of social organisation including the role of women		Information regarding activities could not be obtained.
		Establish a national IK register		IK register established through NIKMAS.[55]
		Audit customary practices from the perspective of compliance with the Constitution		While an audit of the state of IKS was conducted, it is unclear whether it involved auditing customary practices from the perspective of compliance with the Constitution.
		Identify IK and IKS information held in the databanks of public, academic and research institutions, and promoting the fair and equitable use of such IK		NIKSO successfully completed a national audit of databases with IK content.
		Investigate and identify in consultation with indigenous communities the different forms of ownership of IK, the existing mechanisms for the protection of IK and IKS in terms of customary practices and laws of such communities; and designing systems and procedures necessary for recognition and protection of each form of ownership and benefit sharing principles and guidelines		While one of the functions of the IKS Act of 2019 is to "develop and enhance the potential of indigenous communities to protect their indigenous knowledge" it is unclear whether the investigation took place. Concern was also raised regarding the Act that "There was inadequate consultation between the Department and traditional health practitioners and indigenous communities."
	Integrate IK into other policies	IKS should be integrated into the National Human Resource Development Strategy, the National Skills Development Strategy, and the Integrated Sustainable Rural Development Strategy.		IK is not mentioned in any of the three policies.

[54] 2IKS Documentation Centre.
[55] National Indigenous Knowledge Management System.

Strategic objectives	Interventions	Activities		Comments
Establish funding for IKS	Establish an IKS Fund	-		A trust fund for IKS was established and funded during 2004/05.
	Targeted IKS funding streams	Appropriate IKS funding streams that support, among others, curriculum development, small business development based on IK, public understanding of IKS, IK practice and accreditation, research and development, IK innovation, IK protection, and IKS Centres.		Aside from the NRF funding instrument for IKS, unable to obtain further information about these other funding streams .
	Funding to support IK cataloguing	Support institutions that will assist indigenous and local communities in the categorisation and characterisation of their biological resources, innovations, practices and technologies.		IKSDCs by DST implemented by the CSIR.
	Grants for agricultural and industrial enterprises related to IK	Provide a wide range of grants and incentives principally to cater for the medium- and long-term needs of agricultural and industrial enterprises, particularly in the rural areas, with emphasis on small and medium-sized industries.		Unknown whether grants were provided and through which funding agency.
	Funding for co-operative IKS ventures	Fund linkages and access to existing programmes that augment grassroots innovations by providing opportunities for experimentation, scaling up, prototype development and establishing relevant infrastructure. Co-operative ventures between indigenous and local communities, schools, industry and other community organisations to enhance employment outcomes.		DST developed "model whereby it organised communities into SMMEs who would then enter into tight joint venture agreements with bigger companies" (PMG, 2016)[56]
	Create IKS Trust funds	Support the establishment of independently based organisations such as Trust funds, to cater specifically for the needs of particular stakeholders.		Unknown.
	Financially support grassroots innovators in IK	Assist financially improving the capacity of grassroots innovators such as small-scale farmers, artisans, women and labourers in dealing with distant markets and utilising various market and nonmarket opportunities for upgrading their skills, perspectives and resource base.		No funding mechanisms at grassroots level have been introduced (expert feedback).

[56] PMG. 2016. Indigenous Knowledge Systems: Department of Science and Technology and Department of Trade and Industry inputs. Available at: https://pmg.org.za/committee-meeting/23085/.

Strategic objectives	Interventions	Activities		Comments
	Funding for IKS Centres and IKS laboratories	Support tertiary institutions in the establishment of IKS Centres and IKS laboratories, and assist existing ones in the promotion, development and protection of IKS.		SARChI Chairs in IKS and CIKS funding by NRF.
Develop policy and legislative regulatory framework to support IKS	Develop minimum standards for benefit-sharing in IK	Information Transfer Agreements and Material Transfer Agreements that conform to a minimum standard should be required for all researchers in the field of IK to ensure a basis for future benefit sharing in the absence of a recordal system.		Benefit-sharing stated as a requirement in NRF IKS programme, and the IK Act requires benefit-sharing agreements for any use of IK.
	Amend South African patent law related to IK	SA Patents Law should be amended to formally require declaration of the use of IK or the transfer of materials arising from the indigenous use in the prior art declarations in respect of patents and designs.		IK recognised as prior art under IP laws.
	Establish feasibility of regional IPR bodies	South Africa, in partnership with other African countries, needs to investigate the feasibility of establishing unifying continental or regional bodies which not only address the protection and rights of an Intellectual Property System, but move beyond this to develop other appropriate instruments for IK protection.		Insufficient information to assess.
Develop IKS human resource capacity	Integrate IKS in the National Qualifications Framework	NIKSO should address elements of IK that are not readily accommodated within the NQF. Every attempt should be made to harmonise the national accreditation process with international processes.		Policy framework for an accreditation and certification system drafted in 2011, but no evidence that it was formally approved by Minister.
		The DoE should take steps to begin the phased integration of IK into curricula and relevant accreditation frameworks.		CIKS involved in curriculum development.
		Develop clear knowledge validation frameworks that inform the education system.		Goal too vague to evaluate.
	Promote research capacity building in the universities for IKS	Promote research capacity building in the universities.		CIKS and associated partners involved in capacity building.
	Form private-sector partnerships with indigenous communities	Form partnerships with indigenous communities based on novel IK-based products (e.g. in the pharmaceutical and music industries)		CIKS, NRF and CSIR involved with projects.

Strategic objectives	Interventions	Activities		Comments
	Form private-sector partnerships with indigenous communities	Establish SMMEs, particularly in rural areas, that are based on research development, innovation and commercialisation of IKS		45 IK-based SMMEs created.
	Promote IKS as an employment generator	Create businesses based on IK services resulting		Examples of cases and internships by CIKS.
	Public understanding and awareness of IKS	DST to develop a strategy for public understanding and awareness of IKS		DST IKS public awareness campaigns.
	Develop skilled IKS researchers and managers	Develop a flow of highly skilled researchers and IKS managers, who understand research and IK development as well as innovation, technology transfer and diffusion from the viewpoints of industry, government and academia		Bachelor of Indigenous Knowledge System (BIKS) first graduates in 2018, training of research managers.
	Train blacks and females in IKS fields	Train an increased number of blacks and females to follow careers in the various IKS fields		The number and percentage of female students at CIKS increased between 2014 and 2017. However, figures for the numbers of black students are not provided in the self-assessment report.
	Support school-based and adult education in IKS	Support school-based and adult basic education initiatives geared towards mobilising IK in multicultural contexts of learning		Initiatives by CIKS.
Create an information and research infrastructure for IKS	Develop IKS databases	Methodology and standards used in the creation of IK databases should be harmonised with other international systems so that cross-referencing is possible.		NIKMAS developed in stages (National Recordal System website).
		Establish appropriate regulating mechanisms, which can develop the protocols and codes of conduct on the documentation and use of IKS resources.		IK Act of 2019 provides legal framework, NIKMAS the implementation of the documentation.
		IK databases should be created.		NIKMAS and IKSDCs created.
	New model for libraries in relation to IKS	Facilitate indigenous and local community information access based on their own identified needs.		Achieved through IKSDC.

Strategic objectives	Interventions	Activities		Comments
		Provide opportunities for indigenous and local communities to actively record and share their contemporary history, culture and language with both indigenous and non-indigenous peoples.		Achieved through IKSDC.
		Develop strategies for regional sharing of such resources and for supporting specialist libraries in particular subjects, based at the centres of excellence.		IKSDC created, although additional need identified by CIKS (2018).[57]
	Role of museums for IKS	Investigate possibility of establishing an IKS museum with a strong public awareness orientation.		Evidence that museums are involved with public awareness of IKS in DST annual reports.
		Define and encourage the research role of museums.		Museums are mostly absent in recent DST annual reports.
	Preservation of oral forms of IK	Mechanisms to be put in place to retrieve and preserve oral forms of IK to contribute to national archive material.		Need more data regarding these projects.
		Through DAC, matters relating to oral forms of IKS to be researched, developed and promoted as part of South Africa's intangible heritage.		Need more data regarding research in the field.
	Establish IKS laboratories	Establish special laboratories for the development of IK, in addition to integrating IK research within existing research institutions.		No evidence for this could be established.
		Generate knowledge through interdisciplinary and participatory action research, case studies and promotion of community development experiences.		Need more data regarding research.
		Facilitate methods such as participatory technology development, community and culture based resource management, and area management planning.		"IRD is a flagship unit for promoting excellence in participatory action research…" CIKS (2018: 9)
		Contribute to research by and for indigenous peoples.		Need more data regarding published research
		Contribute to capacity building to establish priority research topics and to direct research activities.		Priority areas identified by CIKS.

[57] CIKS. 2018. *DST-NRF Centre Indigenous Knowledge Systems (CIKS) evaluation report: Management response.* Available at: https://www.nrf.ac.za/sites/default/files/documents/Management%20Response%20CIKS%20Oct2018.pdf.

Strategic objectives	Interventions	Activities		Comments
		Develop human resource through training and learning by enhancing capacity of research professionals, local technicians, resource managers and farmers, mainly from local and indigenous communities, on biodiversity conservation, community development, watershed management and cultural revival.		Activity too broad, more data regarding different training programmes required (not just graduate programmes).
	Establish IKS centres	It is proposed that the establishment of IKS Centres within existing structures such as universities, community centres, etc. will act as a facilitating and enabling mechanism, and their services, programmes, and projects should involve broad participation and collaboration of members of local and indigenous communities.		CIKS established with projects that involve indigenous communities.
		Collect, document, and disseminate information on various components of indigenous knowledge.		CIKS uses their communication linkages to disseminate IKS information.
		Develop cost-effective and reliable methodologies for recording indigenous knowledge.		IKS National Recordal System established.
		Conduct training programmes and design materials on IK for development workers in IKS, practitioners and holders.		CIKS is working with the Gaqa School of Traditional Medicine (TM) in Umlazi, Durban, to promote an Integrated TM Training Programme.
		Conduct interdisciplinary research on IKS.		CIKS multi- and transdisciplinary research projects.
		Promote the establishment of regional and national IK resource centres.		IKS documentation centres part of IKS CoE initiative (e.g. KwaZulu-Natal IKSDC).
		Assist in the formulation of policies and design technical assistance programmes based on indigenous knowledge.		CIKS has assisted with developing provincial and institutional IKS policies in KwaZulu-Natal and at UKZN.
	Develop a research agenda for IK	Develop a clearly articulated research agenda for IK, based on the articulation of desired research priorities and outputs.		CIKS have research focus areas.
	Intensify IK and IKS research	Intensify R&D work in this area, particularly as it relates to recording and supporting traditional healers on safety and accessibility, among others.		Vague formulation and multidisciplinary nature of IKS render this challenging to measure.

As highlighted in the introduction, this review has been somewhat limited in scope owing to the fact that it has relied upon an assessment of a policy rather than a strategy and associated implementation. In addition, in the absence of any reviews of the IKS programme of activities as a whole, this review has not had the benefit of gathering additional information from previous reviews. The conclusions drawn about the implementation of the IKS Policy therefore provisional as they are based on information available at the time of the review.

On this basis, our assessments show that, in the main, the policy objectives have largely been achieved. The objective of creating an institutional framework has been achieved through the establishment of NIKSO in 2006 and the Ministerial Advisory Committee on IKS in 2008. For the purposes of this review, however, it has been difficult to assess the implementation of the functions associated with these bodies owing to a lack of sufficient information in this regard.

The objective of establishing an infrastructure of public funding for IKS has largely been achieved via the introduction of the IKS Fund, NRF funding instruments, funding to support IK cataloguing through the IKS documentation centres, and funding for IKS centres and IKS laboratories via the creation of a SARChI and CoE in IKS. However, owing to a lack of information, it has not been possible to assess the full spectrum of funding required and therefore ascertain whether or not the public funding for IKS has been sufficient.

Developing a legislative and regulatory framework for IKS has also been achieved in terms of the development of minimum standards for benefit-sharing in IK, and the amendment of South African patent law related to IK. Overarching legislation relating to IKS in the form of the Protection, Promotion, Development and Management of Indigenous Knowledge Act No. 6 of 2019 is also in place – although some 15 years after the publication of the IKS Policy.

Significant inroads in relation to the objective of developing IKS human resource capacity have been made with regard to promoting research capacity building in the universities for IKS, forming private-sector partnerships with indigenous communities, promoting IK as an employment generator, promoting public understanding and awareness of IKS, developing skilled IKS researchers and managers, and supporting school-based and adult education in IKS.

Finally, the objective of creating an information and research infrastructure for IKS appears to have been less successful. Aside from establishing IKS centres and developing a research agenda for IK, activities relating to developing IKS databases, a new model for libraries in relation to IKS, and the role of museums in IKS appear to have been only partially achieved.

CHAPTER 4

TECHNOLOGY STRATEGIES AND MISSIONS

4.1 Introduction

The core of the NRDS is based on three pillars: innovation, SET human resources and transformation, and the creation of an effective government S&T system. In its discussion of the innovation pillar, the NRDS identifies a number of technology missions that "are critical to promote economic and social development" (DST, 2002: 16):

> *These include the two key technology platforms of the modern age, namely biotechnology and information technology. Two additional missions are technology for manufacturing and technology to leverage knowledge and technology from, and add value to, our natural resources sectors. Finally, we will establish a mission, technology for poverty reduction, to address one of the scourges of our age.*

The paragraph concludes that the FTI would play a central role as a knowledge-based financing agency concentrating on innovation within each of the technology missions: "It will fund innovation across the public and private sectors, and across the value chain from concept to market – though, with a key focus on high-cost development and market acceptance stages through commercialisation, incubation and diffusion" (ibid.).

In a more detailed discussion of the technology missions in Chapter 5, the NRDS makes reference to four main technology missions:

- Poverty reduction, with a focus on demonstration and diffusion of technologies to impact quality of life and enhance delivery;
- Key technology platforms, with a focus on knowledge-intensive new industries – specifically biotechnology (linked to the 2001 National Biotechnology Strategy) and ICTs;
- Advanced manufacturing (linkages to the Integrated Manufacturing Strategy); and
- Leveraging resource-based industries and developing new knowledge-based industries from these (mobilising the power of existing sectors).

In the TYIP, the focus shifted from identifying specific technology missions to an emphasis on the role of technology development and innovation as a cross-cutting enabler (together with human capital development and knowledge infrastructure) for the five grand challenges. This is clearly demonstrated in passages such as the following (DST, 2008):

South Africa must seize the opportunities now available in areas such as biotechnology, nanotechnology and the "hydrogen economy" to establish capabilities that will provide long-term, sustainable solutions in national priority areas such as health and energy, while boosting economic growth. (p13)

Over the next decade South Africa must work to become a world leader in biotechnology. Since the introduction of the first commercial genetically modified crops in 1995, more than 400-million hectares have been planted, 40 percent of which are grown in the developing world. And it is in the developing world where the need for biotechnological innovation to solve basic problems, from health care to industrial applications, is most apparent. (p20)

The development of a space technology programme provides an opportunity to use satellites to conduct astronomy observations from space. Telescope-loaded satellites will be geared to complement terrestrial research in global partnership programmes. Tracking stations able to download data from satellites will position South Africa as a competitive location attracting international investment. (p24)

The shift in the narrative from the NRDS to the TYIP does not necessarily signify a shift in emphasis or importance. But it does demonstrate the difference between a more 'technocratic' – even 'linear' – approach to the role of technology in development (NRDS) and an approach where technology serves the demands for inclusive development in society. This shift is perhaps analogous to the shift from defining technology in terms of clearly demarcated 'technology push-missions' to seeing technology as a cross-cutting and enabling platform. Three technology strategies were explicitly identified in the NRDS and TYIP: advanced manufacturing and mineral beneficiation, ICTs, and nanotechnology (the latter in the TYIP). While biotechnology is referred to in the NRDS, in the TYIP it was subsumed under the Farmer to Pharma Grand Challenge (later renamed as the Bio-economy Grand Challenge). We discuss this grand challenge in the following chapter. According to our knowledge, 'technology for poverty reduction' was never managed as a separate strategy. Inspection of the DST expenditure reports show that an annual amount was allocated to this domain up until 2010 after which it was renamed 'innovation for inclusive development'.

4.2 Advanced manufacturing and resource-based technologies

4.2.1 Context, overview and strategic objectives

The NRDS specified the development of new knowledge-based industries as one of five technology missions, and also stressed the importance of leveraging resource-based industries, assigning separate budgets for each area. Each mission followed separate but also overlapping pathways of implementation. Much of the intent for technology for advanced manufacturing can be found in the planning documents of the Advanced Manufacturing Technology Strategy (AMTS), which later evolved to a specific project area within the Technology Innovation Agency and also became the core focus of the Advanced Manufacturing Technology Directorate within the DST. An analogous strategy for resource-based industries was never developed. Instead, it appears that these objectives were incorporated into three other strategies or strategic focus areas, namely advanced metals (which includes various initiatives in precious metals, light metals, ferrous and base metals, and new metals); mining and minerals (which includes initiatives such as the South African Mining Extraction Research, Development and Innovation Strategy); and chemical industries (which was mainly directed into the Fluorochemical Expansion Initiative). These latter focus areas are discussed at greater length in the full review (Volume 5: Annexure 14). For the purposes of this chapter, the focus is on the advanced manufacturing technologies.

It is apparent that advanced manufacturing was considered to be an important part of the NRDS, and the successful implementation thereof critical to the NRDS's achievement. Similar sentiments were also stated in the TYIP, which expanded on the problem statement with the argument that "the domestic market for medium-high technology products and services on the one hand, and local research on the other, had nothing in common" (DST, 2008: 22). The intention of both the TYIP and NRDS was to build local capability in R&D which could support and grow South African manufacturing and other sectors. The process imagined a gradual separation of the technology user from a dependence on international technology transfer. Generally, the TYIP positioned R&D-led innovation (rather than technology transfer) as important in the technology missions, particularly those sectors already identified by other strategies as being core to the transformation of the economy from resource-based to knowledge-based, such as advanced manufacturing technologies, "smart" materials and metals, advanced ICT, 4th generation nuclear reactors manufacturing, and chemicals technology. This theme is core to the overall theory of change in the TYIP.

Much of the initial activity in this area was assigned to the AMTS, which was adopted by Cabinet in 2003. The AMTS links closely to the dtis 2002 Integrated Manufacturing Strategy which, together with the NRDS, highlighted the importance of technological innovation and high-end human resource development as a means of shifting the manufacturing sector from being based on raw material-intensive outputs towards increasingly knowledge-intensive goods and services.

The goals of the AMTS included to: contribute towards national economic growth; contribute towards the economy's transition to a knowledge-based economy; and improve the sector's competitiveness through advanced manufacturing and innovation. The strategic objectives of the AMTS are listed below.

Strategic objectives of the Advanced Manufacturing Technology Strategy

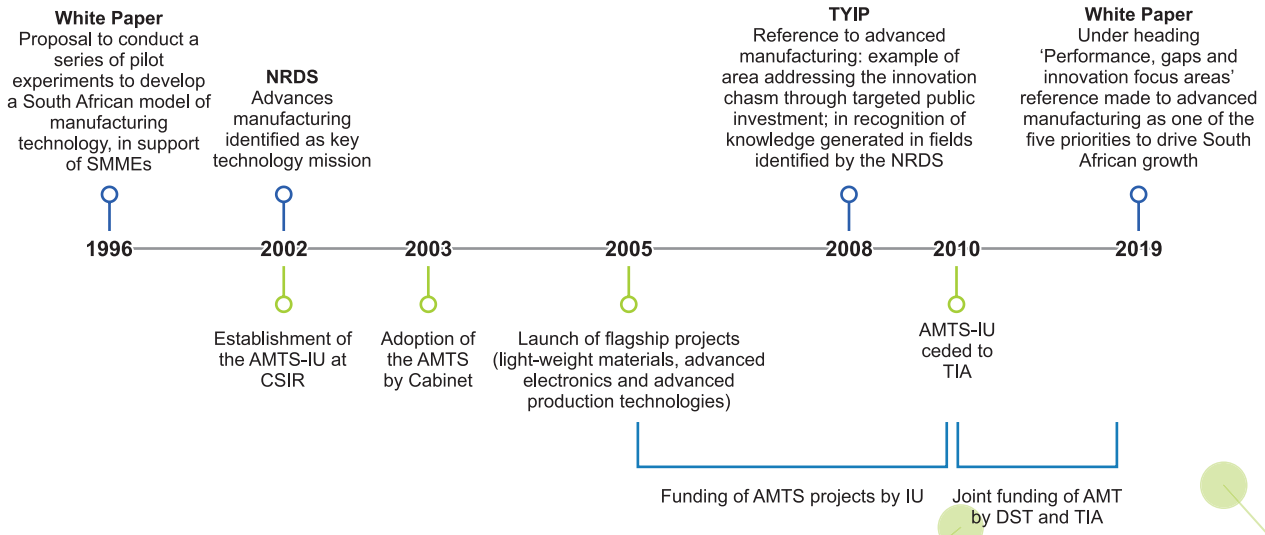
Mission	This strategy is intended to improve the competitiveness of the industrial sector, as defined in technological terms, and contribute towards the country's transition to a knowledge-based economy	
Strategic objectives	1	Identify priority sectors which have the greatest potential for supporting relevant goals contained in the IMS and the NRDS, such as job creation and equity
	2	Stimulate technological upgrading in industry
	3	Facilitate the flow of technological resources to industry through new knowledge networks to foster innovation
	4	Facilitate the building of an environment conducive to innovation, particularly through the supply of skilled manpower, technology infrastructure and funds

The strategy identified three implementation mechanisms to achieve its goals, namely to: (1) strengthen existing or establish new centres of innovation; (2) strengthen existing or establish new innovation networks; and (3) establish targeted R&D initiatives, projects or programmes.

Development and implementation of the AMTS was assigned to the AMTS Implementation Unit (AMTS-IU), which was established at the CSIR in 2002. Apart from playing a general advocacy role for advanced manufacturing across all the target sectors, the AMTS-IU also established three flagship programmes in the areas of Lightweight Materials, Advanced Electronics and Advanced Production Technologies. The flagships were introduced in order to focus the R&D efforts of the AMTS so as to ensure measurable outcomes were achieved, and to align individual projects to the original aims of the AMTS. Other initiatives of the AMTS-IU included establishing the Fabrication Laboratory at the Innovation Hub (FabLab) and the Advanced Manufacturing Technology Laboratories (AMTLs), and support for human resource development through the Programme for Industrial Manufacturing Excellence (PRIME) and Leading Expert Access Programme (LEAP).

Key developments relating to advanced manufacturing technologies are captured below.

Key developments relating to advanced manufacturing technologies



4.2.2 Assessments

Our assessment of the strategy design is provided below.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of the strategy design

Is any reference made to problems or challenges being addressed by the strategy?		Yes; there is a section on the importance of industry and technology upgrading in order to realise the necessary competitiveness. The three reasons for the strategy are the higher value of such manufacturing; the link with high growth; and the need to diversify a minerals-based economy.
Are the goals and objectives clear and unambiguously formulated?		The goal statement is clear, as are the high-level objectives.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		Yes. The implementation of advanced manufacturing objective of the NRDS was initially assigned to the AMTS-Implementation Unit, and subsequently to the TIA. The DST also developed in-house capability to manage the other three areas, and specifically the initiatives in titanium, additive manufacturing and fluorochemicals.
Is a budget for the interventions provided?		Yes; in both the NRDS and the AMTS.
Are targets and milestones included?		No clear targets or milestones are set other except for three relating to improvement of the country CIPI; technology intensity per capita; and R&D spend as % of GDP (GERD).
Are intervention outputs clearly specified?		No outputs are specified.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		The advanced manufacturing technology mission was explicit in terms of its intended outcomes (economic growth and diversification). However, such a high-level definition of the objectives was clearly insufficient in being able to ensure the intended outcomes. This failure is the consequence of both a limited mandate by the DST to influence the sector, and the extreme nature of the problem. No distinction between short- and medium-term outcomes.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		Only three indicators are provided in the strategy relating to improvement of the country CIPI; technology intensity per capita; and R&D spend as % of GDP (GERD).

The next table contains an assessment of the qualitative outputs from the AMTS. The quantitative metrics (actual values in 2002, targets for 2014 as per the AMTS, and actual values in 2018) follow.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of the AMTS qualitative outputs

No.	Activity		Comments	Evidence
1.1	Focus on priority sectors which have the greatest potential for supporting relevant goals contained in the IMS and the NRDS		Completed in the initial phase of AMTS	AMTS reports
2.1	Establish the AMTS and the Implementation Unit		Completed in 2003	AMTS reports
2.2	Stimulate R&D within private firms		Limited response to system efforts	World Bank study
3.1	New knowledge networks to foster innovation		No evidence of a positive change	NACI reports
4.1	Supply of skilled labour		University graduates increasing	CHET reports and others
4.2	Supply of technology infrastructure		Infrastructure somewhat improved	NRF reports
4.3	Provision of sufficient financial resources		The system is still resource-constrained	National R&D Survey

Although this is not explicitly stated in any of the AMTS documents, it is assumed that items 2.2, 3.1 and 4.1 would be addressed through the R&D programmes of the AMTS. The output measures of the R&D programmes included: human capital development (postgraduate students supported); publications (peer-reviewed journal or conference papers); and intellectual property portfolio (patent applications, granted patents, prototypes, technology demonstrators). No information is available on the extent to which the AMTS achieved its targets in each of the latter areas, or indeed whether such targets were ever defined. The only quantitative targets which could be used to assess the achievements of the strategy are those as listed below.

Quantitative metrics for the AMTS[58]

No.	Indicator	Owner	Initial value (year)	Target value (year)	Actual value (2018)
3.1	Improvement of the country CIPI	AMTS/DST	0.1 (2002)	0.2 (2014)	0.072 (2014)
3.2	Technology intensity per capita	AMTS/DST	US$17 (2002)	US$30 (2014)	Not available
3.3	R&D spend as % of GDP (GERD)	DST	0.76% (2002)	1.5% (2014)	0.8%

Summary implementation scorecard for the AMTS

Strategic objective	Intervention	Assessment
1	Focus on priority sectors which have the greatest potential for supporting relevant goals contained in the IMS and the NRDS	
2	Establish the AMTS and the Implementation Unit	
	Stimulate R&D within private firms	
3	New knowledge networks to foster innovation	
4	Supply of skilled labour	
	Supply of technology infrastructure	
	Provision of sufficient financial resources	

The emphasis placed by the DST on diversifying and intensifying (from a knowledge perspective) the South African manufacturing sector was well-founded. Growth of the sector in terms of value added and employment is absolutely critical for the economic and social prosperity of the country. Notwithstanding the importance of this outcome, innovation policy has had a limited impact on the sector and the revitalisation of manufacturing remains elusive. Innovation-led growth, particularly in manufacturing, has consistently under-performed relative to the achievement of the cohort of countries within which South Africa is normally assessed.

[58] The figures in this table derive directly from page 30 of the AMTS Strategy (Volume 1), with the correction for GERD from 0.7% to 0.76% (the former value was incorrectly reported) and hence the 2014 doubling target from 1.4% to 1.5%.

The manufacturing sector's share of GDP has declined over time: from being the largest broad sector of the economy in 1994 (21% of overall GDP), its contribution dropped to 13.2% by 2018, and is now ranking in 4th position.[59] Based on the suggested metrics of the AMTS, namely the UNIDO's CIPI, the profile of the country's manufacturing sector and the composition of its manufactured exports has progressed little since the launch of the NRDS.[60] South Africa has largely stagnated in respect of the diversification and intensification of its manufacturing sector.

It would be incorrect to place culpability for the decline in the manufacturing sector entirely on a weakness in the policy framework, and particularly the 'industry development' aspects of the NRDS. As indicated in this review, there are gaps in the NRDS from the perspectives of both the design of the strategy and how it was implemented. The most positive aspect of the NRDS is that it highlighted the plight of the sector, and the need for knowledge intensification, technology transfer, raw material beneficiation and localisation, and directed the focus of the DST to addressing the stabilisation of the sector within the mandate of the Department. In the years that followed, the structural failings of the AMTS, as DST's first implementation step of the NRDS industry development objective, became irrelevant in the broader objectives of the DST. Other strategies replaced the AMTS and developed a momentum of their own, covering a broad set of sectors, including mining, manufacturing and materials.

In summary, the stated objectives of the industry development intent of the NRDS – namely to contribute towards the economy's transition to a knowledge-based economy, to improve the sector's competitiveness through advanced manufacturing and innovation, and to leverage resource-based industries – have not been altered despite more than 15 years of sustained effort by the DST and its agencies.

It is possible that this assessment is about to change. If the present initiatives in fluoride-based electrolytes, titanium powder, additive manufacturing and others are successful, the sustained efforts of the DST and its partners will have been vindicated. Moreover, the introduction within the DST of portfolio and project management approaches, such as the approach of TRL, will help to mitigate the risk of technology-led development and improve the likelihood of success. However, the size of the challenge cannot be underestimated, and although many government departments need to take responsibility for the persistent failure to develop value-adding industries in South Africa, part of the culpability certainly lies with the DST's inability to develop a clear implementation plan with milestones and targets. Such a document is highly recommended as a way forward for the department's implementation of the technology missions.

4.3 ICT strategy

4.3.1 Context, overview and strategic objectives

While not accorded significant emphasis, the 1996 White Paper on S&T called for the promotion of an information society (DACST, 1996: 12). The ICT Panel that formed part of the National Research and Technology Foresight study in early 1996 noted that the ICT sector was "unique because it represents a scientific discipline and industry in its own right, as well as cutting across all other sectors" and suggested that "the various priorities and future needs would best be captured into ten Strategic Technology Nodes covering 'Future Web,' Intelligent systems, Knowledge and learning, and public/private collaboration" (DACST, 1999: 48).[61]

In 2002, the NRDS declared ICT as a fundamental platform technology. The NRDS highlighted a number of specific foci for ICT,[62] as well as intensification of ICT use in resource-based industries and manufacturing, and the use of earth observation (satellite and aerial) data to support government, industry and SADC in key areas.[63] Other areas relevant to ICT would be microsatellite engineering and encryption technology.[64]

In 2007, the DST published the *Information and Communication Technology Research and Development and Innovation Strategy*, which articulated its vision as follows (DST, 2007: 2):

[59] Walwyn D. 2019. *Why South Africa should revert to greater protection for some of its industries. Conversation Africa*. Available: https://theconversation.com/why-south-africa-should-revert-to-greater-protection-for-some-of-its-industries-120103.
[60] UNIDO. 2019. Competitive Industrial Performance Report 2018. Vienna: UNIDO.
[61] DACST. 1999. All our Futures. Pretoria: Department of Arts, Culture, Science and Technology.
[62] These included: automatic language translation technologies; low-cost telephone and e-mail integration; low-cost integration of satellite telephony and the Internet; robust distributed computing services; open-source software initiatives; participation in high bandwidth global experiments; and participation in developing country initiatives to reduce the cost of basic computer hardware.
[63] For example, in relation to disaster prevention, monitoring and remediation; mapping and GIS services; agriculture services; and land-use and urban development services.
[64] The focus on encryption technology has since evolved into a stronger attention to the broader arena of cybersecurity.

South Africa is an inclusive information society where ICT-based innovation flourishes. Entrepreneurs from historically disadvantaged population groups, rural communities and the knowledge-intensive industry benefit and contribute to the well-being and quality of life of our citizens. South Africa has a strong national ICT brand that captures the vibrancy of an industry and research community striving for excellence, characterized by innovative approaches to local and global challenges, and recognized for its contribution to the economic growth and well-being of our people and the region.

The overall purpose of the ICT RDI Strategy is stated as "to create an enabling framework for the advancement of ICT R&D and innovation, in a systematic fashion, within the context of the National R&D Strategy" (ibid: 17). The strategy outlined three strategic objectives and four supporting objectives towards realisation of its vision.

ICT RDI Strategy strategic and supporting objectives

Mission	The mission of this strategy is to contribute to significant improvement in the quality of life and the creation of wealth for the people of South Africa, especially the historically disadvantaged, by creating a coherent, integrated and well administered ICT R&D and innovation system of partnerships, financing, processes, policies and infrastructure	
Strategic objectives	1	Develop focused world-class research
	2	Build a strong and robust innovation chain
	3	Build advanced human resource capacity
Supporting objectives	1	Establish and maintain an effective research infrastructure
	2	Foster vibrant international cooperation
	3	Provide ICT policy, institutional and other support
	4	Adequately resource the ICT R&D and innovation system

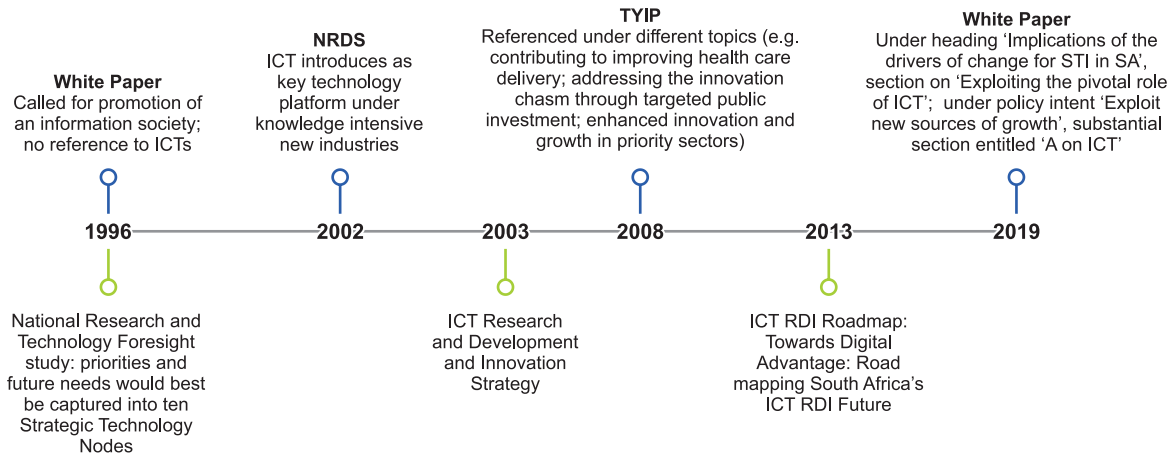
The strategy details a number of "strategies and actions" that support each objective, as well as nine proposed "interventions" – Advanced Human Capital Development Programme; Critical Mass Research Programme; International ICT R&D Collaboration Programme; Large Innovation Initiatives and Grand Challenges; ICT R&D in Industry Programme; ICT R&D and Society Programme; R&D Infrastructure Programme; Futures Research, Future Technologies and Strategy Implementation and Renewal Support; Funding the ICT R&D and Innovation Strategy.

The 2008 TYIP gave little advocacy to ICT or even information infrastructure, making only passing references to ICT in relation to topics such as contributing to improving health care delivery, addressing the innovation chasm through targeted public investment, and enhancing innovation and growth in priority sectors. The ICT platform was incorporated into the Space Science and Technology Grand Challenge.

Six years after the publication of the ICT RDI Strategy, the DST/CSIR developed the 2013 *ICT RDI Roadmap: Towards Digital Advantage: Road mapping South Africa's ICT RDI Future*. The Roadmap is intended to provide "a coherent, comprehensive and flexible ten-year implementation framework to coordinate and manage ICT research and technology development nationally, regionally and in relation to our international partners" (DST/CSIR, 2013: 4). The central concept of the ICT RDI Roadmap is that of 'digital advantage'. The Roadmap identified key market opportunities for ICT which were grouped into six clusters: broadband infrastructure and services; development; sustainability and the environment; grand science; industry applications; and the service economy.

The timeline of key national-level developments relating to ICT is captured below.

Timeline of national-level developments relating to ICT



4.3.2 Assessments

Our assessment of the strategy design is provided in the table below.

Well addressed

Moderately well addressed

Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy/plan?		Yes. The ICT RDI Strategy notes that "South Africa has not been investing in ICT R&D and innovation nearly as much as other major economies"; "Optimal utilisation of ICT for such social and economic benefits requires vigorous and focused research and innovation activity, as well as a strong skills and knowledge base"; various international and local trends "indicate the need for a comprehensive national approach to ICT R&D and innovation"; and that South Africa faces various challenges in "in the development of an effective national approach" to ICT RDI (DST, 2007: 14-15). The nine proposed interventions also include an analysis of the problems or challenges each intervention is intended to address. The ICT RDI Roadmap notes deficiencies relating to R&D expenditure and the human capital pipeline (see DST/CSIR, 2013: 12).
Are the goals and objectives clear and unambiguously formulated?		On balance, the stated goals in the NRDS and the ICT RDI Strategy lack precision. Similarly, the subsidiary objectives of the NRDS, ICT RDI Strategy and ICT RDI Roadmap.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		The strategy contains a long list of "strategies and actions" associated with each strategic objective and supporting objective. In addition, it lists nine interventions. While there are overlaps between the two, they do not necessarily correspond. Arguably, only some of the strategies, actions and interventions are measurable. The strategy provides a detailed list of the role-players and their roles in implementing the strategy. However, these are not directly linked to the strategic objectives.
Is a budget for the interventions provided?		A proposed budget is outlined in the strategy, but it only covers the first three years of the strategy (2007/08-2009/10) although the timeline for the strategy reaches to 2016.
Are targets and milestones included?		The only targets set in the strategy relate to PhD graduations, and the only milestones pertain to the intervals between required for reviews and an ICT foresight exercise.

		Roadmap targets were specified, but were unrealistic. High-level timelines were scoped out to 2022 in the Roadmap.
Are intervention outputs clearly specified?		The outputs associated with the nine interventions specified in the strategy are not clearly identifiable.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		The ICT RDI Strategy identifies four intended outcomes: • Achieving global leadership in identified key scientific and technological domains • Developing multi-disciplinary technologies, skills and methodologies to address areas of market neglect, especially to eradicate the digital divide • An indigenous ICT sector that is developed, growing, innovative and competitive • The smart proliferation of ICT within other sectors of the economy. The ICT Roadmap also outlined intended impacts in terms of contribution to the economy, new businesses created and job creation.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		The strategy notes that progress towards implementation will be monitored based on a number of key performance indicators (KPIs) "which will be cascaded to agencies responsible for the implementation of the strategy" (DST, 2007: 64). However, the KPIs only relate to the first three objectives of the strategy: human capital development, focused research, and innovation. These are concrete and measurable: PhD graduation rate; ICT FTE researchers with PhDs; Global ICT publication share; Relative Citation Index; ICT patent share; and ICT BERD (business expenditure on R&D). Financial, firm, and job creation indicators and targets were identified in the Roadmap. While the indicators are clear, the mode of measurement is unspecified.

Assessment of the implementation of the interventions and associated activities for each strategic goal is provided below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of the implementation of the supporting objectives of the ICT RDI Strategy

Supporting objective	Activity		Comments	Evidence
Establish and maintain an effective research infrastructure	Centre for High Performance Computing; SARChI chairs; TENET/ SANReN		This objective has been achieved	Centre for High Performance Computing; SANReN; Meraka
Foster vibrant international cooperation	Signalling to interested parties		Difficult to assess; overlaps with space S&T, but new Amazon, IBM, Mara, Hisense investment important	Multinational Corporation subsidiary presence
Provide ICT policy, institutional and other support	Implement effective policy and other support structures at the DST, its agencies and HEIs in support of the strategy		Insufficient evidence to make a judgement	
Adequately resource the ICT R&D and innovation system	ICT RDI budgets		Budget trails demand	R&D survey does not capture sources of funds

Many universities and science councils have participated in ICT R&D and strategy development. In particular, CSIR Meraka and the South African National Research Network (SANReN) have played major roles in scoping and supporting the broad ICT research enterprise. The five Square Kilometre Array (SKA)-related Research Chairs (Cape Town, Stellenbosch, Western Cape, Rhodes, Witwatersrand, with their planned complement of 20 doctoral and 10 post-doctoral students) will in all likelihood contribute to spill-over ICT development. In addition are the Chairs of Information and Communication Technology for Development at UNISA, and Artificial Intelligence at the University of Pretoria. However, these are necessary, but hardly sufficient to actively grow the ICT sector.

From the R&D perspective, the business sector 'leads' ICT R&D, mainly in that considerable in-house system engineering is performed in the banks, insurance, wholesale and retail industries. This work involves system application development for use within these companies, and generates valuable intellectual property that is usually protected as trade secrets. Most software development in South Africa is for in-house use; 'shrink-wrap' software is a much smaller market, with Sage Accounting the leading brand. There is a thriving market for niche shrink-wrap applications in games, education and tourism. A world-class online gambling developer is Derivco International in Umhlanga. One exception is Discovery Vitality, the health insurer that has a number of Patent Cooperation Treaty and US Patent and Trademark Organization filings to its name. These various innovations might best be classed as falling within the activity of experimental development. The extent of such development in the mobile telephony sector has not been quantified. In Cape Town, Amazon is now the largest ICT house with a large contingent of software engineers who maintain and produce cloud applications.

This summary goes some way toward explaining the growth in recorded R&D expenditure on R&D. It is likely that the recorded figure is an under-estimate of the actual spend. Efforts have been made to draw business sector players into DST-led ICT strategy development. It appears as if the momentum of the early 2000s has dissipated somewhat.

In addition to in-house software development in firms, we can observe the presence of technology hubs that are either software applications producers or digital tech-enabled business and social communities. There are more than 50 such 'tech hubs' in South Africa, with more than 20 each in Gauteng and the Western Cape alone. These tech hubs are located in poorly-resourced and in highly-resourced environments, and provide community space and skills programmes for young, application developers and client firms to interact. In agriculture, digital start-ups in tech hubs are building applications for, among others, pest identification in macadamia nut orchards, and some tech hubs are specialising in financial technologies (Fintech). Sectors where application development could receive much greater attention are public education, public health and postal services.

While South African universities, and entities such as Denel and the CSIR (among others), are engaged in publicly-funded research in the ICT domain, and in many areas of digital innovation including digital mining, the quantum and quality of this research needs to advance significantly in the next decade. South Africa has not yet succeeded in building a strong and robust digital innovation chain, as this would require high levels of local innovation in the private sector, in universities, in tech hubs, and in government itself, with these four major digital innovation players collaborating in interconnected projects and research networks. It is noted that a dedicated digital skills strategy is being prepared for publication by the DTPS for 2020.

For its part, the strategy addresses basic and intermediate digital skills. Areas for building advanced human research capacity include but are not limited to: understanding and mitigating cyber vulnerability, cyber security and cybercrime; educational technologies and applications for schools; and industrial technologies and applications for collaborative techno-human computing including design engineering for robotics and mechatronics.

Sites of software applications development include the more than 50 technology hubs, or 'tech hubs', which exist as collaborative working spaces where young software developers build applications, engage with clients and create small start-up businesses. Developers work on applications of artificial intelligence, data analytics, educational technologies (Edtech), financial technologies (Fintech) and cybersecurity applications. In addition, there are many 'makerspaces' which are engaged in additive manufacturing, using 3D printing, liquid 3D printing, laser cutting and other digitally-enabled machinery, processes and techniques, foundational to South Africa's capacity for rapid prototyping and digital fabrication.

Recent large-scale investments in the ICT industry constitute a sea-change, as shown in the following three examples:

1. The establishment of the R1 billion printed circuit board assembler, Yekani Manufacturing, in the East London SEZ;
2. The R1.5 billion that Indian smartphone manufacturer Mara Phone has committed to a new factory plant in the Dube Freeport SEZ; and
3. The recently approved sale of Altech UEC to Shenzen Skyworth Digital Technology of China.

All three initiatives have an export focus that will cause a shift in the profile of high technology goods as a proportion of manufactured exports. These initiatives point to a major reorientation of the ICT sector, with implications for ICT R&D strategy going forward.

4.4 Nanotechnology strategy

4.4.1 Context, overview and strategic objectives

This review focuses on the *National Nanotechnology Strategy* (NNS) published by the DST in 2006. The NNS was intended to strengthen existing efforts of government in accelerating the role of science in transition and advancement, and to assist in creating an integrated industrial focus and support existing technology missions of the NRDS and dti's 2002 Integrated Manufacturing Strategy. The NNS would further complement the Advanced Manufacturing Technology Strategy, the Biotechnology Strategy and the Skills Development Strategy. The overarching goal and strategic objectives of the NNS are presented below.

Goal and strategic objectives of the National Nanotechnology Strategy

Goal		Draw upon the existing strengths of the national system of innovation while addressing the need to enhance its research infrastructure and to create a workforce for advanced technology businesses that support the country's future competitiveness and enhanced quality of life
Strategic objectives	1	Support long-term nanoscience research that will lead to the fundamental understanding of the design, synthesis, characterisation, modelling and fabrication for nanomaterials
	2	Support the creation of new and novel devices for application in various areas
	3	Develop the required resources human and supporting infrastructure to allow the development
	4	Stimulate new developments in technology missions such as advanced materials for advanced manufacturing, nano-bio materials for biotechnology, precious metal-based nanoparticles for resource-based industries, and advanced materials for information and communication technologies

The strategy includes a list of eight key initiatives which outline what must be done to achieve its goals. These are quite broadly described as providing funding; encouraging cooperation; creating infrastructure; introducing postgraduate programmes; stimulating nanotechnology in industry; creating strategic networks; ensuring that nanotechnology is applied according to best practice; and ensuring open debate and public access to nanotechnology knowledge. The strategy also recommends that a Technology Innovation Network be created to support its implementation, and that the implementation be dealt with after the strategy has been accepted.

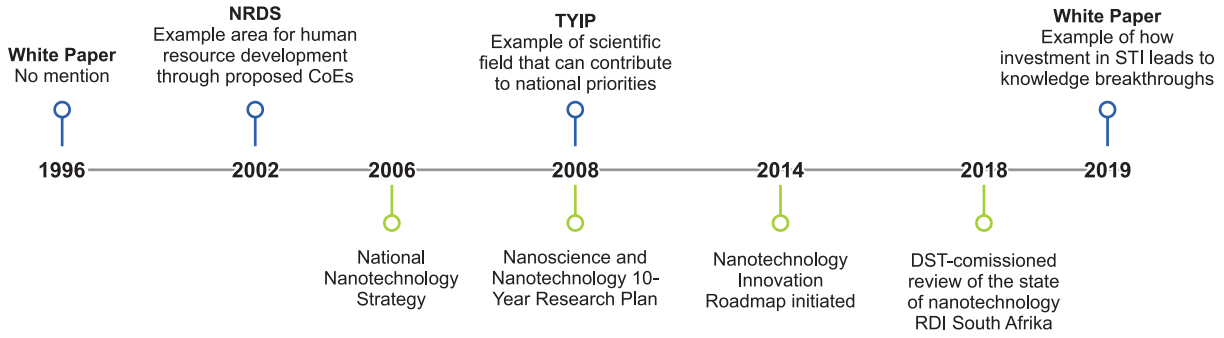
There is no overarching implementation plan for the NNS. However, the *Nanoscience and Nanotechnology 10-Year Research Plan* was introduced by the DST in 2008 to direct the nanotechnology research efforts under the NNS towards priority challenges, and to assist in achieving the strategy objectives. The development of a Nanotechnology Innovation Roadmap was initiated by the DST in 2014; however, it is only envisaged to be finalised in 2020/21.

Nanotechnology was only given passing reference in the NRDS as an example of an area for human resource development through the proposed centres of excellence. Nevertheless, there is clear alignment between the NNS and the NRDS insofar as the NNS advances the technology missions identified in the NRDS, and its success indicators reflect the NRDS objectives in terms of the impact of nanotechnology on improving

quality of life, commercial or economic impact, and promoting human capital development. Nanotechnology was also not a focus in the TYIP, which only referenced nanotechnology as an example of a scientific field that can contribute to national priorities. There is, however, alignment between the Nanotechnology 10-Year Research Plan and the TYIP insofar as the plan includes a section that specifically covers the contribution of nanotechnology to each of the grand challenges.

The key national-level developments relating to nanotechnology are captured in the figure below.

National-level developments relating to nanotechnology



4.4.2 Assessments

Our assessment of the strategy design is provided below.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy?		Yes. The NNS states the intention behind the strategy was to address the problem of the technology divide between developed and developing countries, which is only deepened by advances in nanotechnology. The NNS further underlines its importance in supporting government's goals to create opportunities for human capacity development, the advancement of previously disadvantaged people, drive R&D, innovation, education training and curriculum development, entrepreneurship and black economic empowerment opportunities.
Are the goals and objectives clear and unambiguously formulated?		Yes; the NNS articulates a clear vision to enhance research infrastructure and create a workforce for advanced technology businesses, in support of South Africa's future competitiveness and increased quality of life for citizens. It outlines four specific strategic objectives.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		Yes; the intervention activities are clearly described in the NNS. However, agency is not attributed in the strategy at all. The 10-Year Research Plan does mention specific bodies or programmes involved in certain aspects of implementation, but these are not linked overtly to specific objectives or interventions.
Is a budget for the interventions provided?		The NNS does provide an estimated budget but only for the first three years of the strategy (2006/07-2008/09).
Are targets and milestones included?		The success factors in the NNS are all broad without any specific details relating to how they are to be measured. No milestones are stipulated, nor any means of measuring any of these factors.
Are intervention outputs clearly specified?		The NNS outlines seven critical success factors. The 10-Year Research Plan provides more detail in this regard.

Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		The 10-Year Research Plan lists expected outcomes per impact sector (social development, economic growth and human capital development). The NNS divides the projected impact into short- (1-3 years), medium- (3-10 years) and long-term phases (10 years and longer).
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		Some of the outcomes in the Plan contribute directly to the NNS success factors and provide the detail of how these are to be achieved and measured, although not all success factors have specific indicators. The outcomes listed, however, are generally specific in what they require and in some cases include actual number indicators for outcomes.

Assessments of the implementation of the four strategic objectives and eight key initiatives outlined in the NNS are presented in the first two tables below, respectively. This is followed by an assessment of the progress towards achieving the expected outcomes of the 10-Year Research Plan, based on the evaluation report of Lewis et al. (2018),[65] as well as a consideration of evidence of the NNS contribution towards the achievement of the NRDS goals.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of the implementation of the strategic objectives of the NNS

Strategic objectives		Evidence	Comments
Support long-term nanoscience research		• Large increase in publication numbers and citations in the field (Lewis et al., 2018; Makhoba & Pouris, 2017),[66] increase in nanotechnology patents (Lewis et al., 2018). • Nanotechnology activity evident in most universities (Lewis et al., 2018) and some companies (Botha, 2014).[67]	• Makhoba and Pouris (2017) directly attribute the increase in nanotechnology outputs to the strategy interventions. • Lewis et al. (2018) concur that excellent academic research in the country has been demonstrated.
Support creation of new and novel nanotechnology-based devices		• No evidence of new devices, although some evidence of development towards devices through patents (Lewis et al., 2018). • Some feel that it may be too early to expect device development after 10 years (ibid.).	Molapisi (2019)[68] advised that, with hindsight, this was too specific, and that the intention should have been to create improvements to existing devices rather than develop completely new devices.
Develop human resources and infrastructure to support nanotechnology development		• Increase in nanotechnology workers and students evident, although a shortage of technical staff reported (Lewis et al., 2018). Some transformation achieved.	• Achieved through increases in both students and worker numbers. Potentially issues with a shortage of technical staff and funds to retain staff (Lewis et al., 2018). • 317 people in industry linked to 75 in academia (Botha, 2014).

[65] Lewis Y, Cohen B, Burke M, Harris A, Coetzee K & Logan A. 2018. *Nanotechnology RD&I at Academic Institutions and Science Councils.* Final Report. A report for the Department of Science and Technology.
[66] Makhoba X & Pouris A. 2017. Bibliometric analysis of the development of nanoscience research in South Africa. South African Journal of Science, 113(11/12): 1-9.
[67] Botha AP. 2014. *A Survey of Industrial Involvement in Nanotechnology in South Africa*. TS-109-003-2014-REP 1.0, a report for the Department of Science and Technology.
[68] Molapisi J. 2019. Interview by M Ward on 27 June 2019.

Strategic objectives		Evidence	Comments
		• Equipment supported through the National Nanotechnology Equipment Programme, Nanotechnology Innovation Centre and South African Research Chair Initiative also supported equipment and facilities.	• Equipment supported around the country (Molapisi, 2019).
Stimulate new developments in technology mission[69]		• Little evidence of this development, other than a focus on advanced materials being evidenced by the subject of publications (Lewis et al., 2018).	Molapisi (2019) reported that this was an objective internal to the DST to create alignment around nanotechnology in their own technology missions. It is not clear if this was done.

Assessment of the implementation of the key initiatives of the NNS

Key initiatives		Evidence
Establish dedicated funding for supporting the implementation of the strategy		• R6,251,684,000 funding committed to nanotechnology between 2006/07 and 2016/17, but noted that this is less than provided for biotechnology (CeSTII, 2018).[70] • NIC and NNEP funding streams also created (Lewis et al., 2018).
Encourage multi-disciplinary and multi-institutional cooperation to advance nanoscience and nanotechnology		Little evidence of direct measures taken to encourage this, but there is evidence of joint publications locally.
Develop physical infrastructure to support nanotechnology (including through multi-user characterisation facilities)		• NNEP supported nanotechnology equipment purchased, while NICs developed facilities for national use. SARChI programme also supported capex at various universities. Some criticism of the accessibility of these facilities (Lewis et al., 2018). • Centre for High Resolution Transition Electron Microscopy created. • Lack of prototyping facilities to support commercialisation (Lewis et al., 2018).
Foster the creation of interdisciplinary and inter-institutional nanoscience and nanotechnology postgraduate programmes		• The National Nanoscience Postgraduate Training and Training Programme at the University of the Western Cape (UWC) supports this. • At least one full inter-institutional Masters programme achieved.
Create an environment conducive to collaborative, pre-competitive nanotechnology research and development activities in industry		As per Botha (2014), limited industry engagement is evident.
Support the creation of strategic networks around nanotechnology to encourage collaboration for a multi-disciplinary science		Little evidence of much activity in this regard.
Analysis and introduction of legislative instruments to ensure that nanotechnology is applied according to international best practice in industrial and environmental safety standards		Some support of NIOH work in this regard but not much activity undertaken.

[69] For example, advanced materials for advanced manufacturing, nano-bio materials for biotechnology, precious metal-based nanoparticles for resource-based industries, and advanced materials for ICTs.

[70] CeSTII. 2018. South African National Survey of Research and Experimental Development Statistical Report 2016/17. Cape Town: Centre for Science, Technology and Innovation Indicators.

Key initiatives		Evidence
Ensure that the implementation of the Nanotechnology Strategy occurs in a manner that fosters open debate and public access to information		• Creation of SAASTA National Nanotechnology Engagement Programme supports this. • One public information programme achieved.

The 10-Year Research Plan is concerned mostly with how nanotechnology should be directed in order to provide maximum efficacy for the country. It includes a specific set of expected outcomes according to the three expected impact areas of the strategy. Lewis et al. (2018) have analysed these outcomes against their landscape study of nanotechnology in the country (table below). The assessment legend they utilise is as follows:

- Outcome has been met and exceeded
- Progress has been made towards outcome
- Progress has been made towards outcome

Expected outcomes of the NNS as per the 10-Year Research Plan

Impact area	Expected outcome		Evidence of progress
Social development	Improve access to affordable and quality primary health care by the development of a point-of-care diagnostic kit for the diagnosis of TB and HIV/AIDS		The Mintek Nanotechnology Innovation Centre is working towards this, but no product is yet evident.
	Improve access to affordable and quality primary health care by the development of a Nano-drug-delivery-system for TB and HIV/AIDS treatment		38 publications at various universities address this issue, although no product is evident.
	Access to safe affordable good quality water by the development of a low-cost water filter		Water remediation activity is evident, with 28 publications evident. While a low-cost water filter has been developed at UWC and a membrane facility is being developed at Mintek, no product is evident on the market.
	Access to safe affordable good quality water by the development of a low-cost and water portable water-pollutant sensor		Eight publications in this area are evident, with no further indication of work in this area.
	Access to environment-friendly alternative energy sources by the development of an improved solar energy technology		78 publications and some laboratory-scale research undertaken, but no evidence of any product development.
Economic growth[71]	Mass production and export of gold nanoparticles		Mintek develops and sells gold nanoparticles mainly locally and in small volumes.
	At least one improved exportable process for the beneficiation of metals and minerals, in particular the platinum-group metals		Only four publications in this area; no further evidence of outcomes.
	Establishment of at least two new nanotechnology industries		Three spin-off companies were identified, but not the creation of new industries.[72]

[71] Development of a knowledge-based economy, contribution to job creation, increased foreign investment in nanotechnology R&D, in particular health as well as the mining and minerals sectors.

[72] Maruping (2019) noted that while the three companies cannot fulfil this requirement, it is expected that they could form the basis for such industries, particularly a company like PST Sensors which has a strong patent portfolio.

Impact area	Expected outcome		Evidence of progress
	Significant job creation within the nanotechnology sector		Nanotechnology activities are staffed by 785 jobs at research institutions and 77 jobs in the private sector.
	10 patents		44 patents identified; target exceeded.
	At least three technology platforms		No evidence found of the creation of platforms, although research institutions have extensive local and global collaborations
Human capital development	400 master's degrees and 50 doctoral students delivered		418 master's degrees and 398 PhD students graduated; target exceeded.
	150 publications delivered		5,187 publications; target exceeded.

The overall conclusion from the evidence presented here shows that much has been done to boost nanotechnology research in the country with its outputs showing a marked increase and activities spread across institutions. HCD can be seen similarly with an increase in student graduations and in jobs for nanotechnology workers, with some transformation having occurred. An issue with the lack of commercialisation is noted, however, where the impacts required of the strategy in terms of nanotechnology industry stimulation and product creation to address South African challenges, are not evident. Nanoscience as a field has become entrenched in the South African academic landscape, but does not appear to be yielding the full extent of the outcomes required of the strategy. It was noted generally that, to date, there has been a lack of commercialisation activities being undertaken in nanotechnology, attributed to a lack of know-how, funding and commercial partners (Lewis et al., 2018). This issue is evident on a wider scale than just nanotechnology – the DST's 2019 White Paper on Science, Technology and Innovation acknowledges that the South African performance in innovation has been "relatively flat" (DST, 2019: 12) with the country having been unable to fully realise the benefits from science and technology innovation. The White Paper aims to address this issue to ensure that South Africa is able to move forward in this regard. The concern noted by the reports prior to the introduction of the nanotechnology strategy have therefore not yet been fully addressed by the strategy. The NNS goals have been only partially achieved, in line with the broader picture of the NSI in the country.

Several views have been expressed to ameliorate this demonstrated 'slowness' in the development and commercialisation of nanotechnology in the country. The first is that insufficient time has elapsed since the introduction of the strategy for its full effect to be realised, and also that relatively little has been spent on nanotechnology in the country to date, meaning that it has not been sufficiently supported in order to reach its commercialisation possibilities (Lewis et al., 2018). This view was already expressed in 2012 when Pouris et al. suggested that the government spending on nanotechnology objectives had been misdirected on strategies that try to force early results (too much emphasis on technology transfer), and thus generally do not achieve their desired long-term goals[73]

Maruping (2019)[74] supports this by outlining that there is an insufficient understanding in the South Africa environment as to what commercialisation is, and that it takes much more time and funds to take something to the market than is currently understood. Further she outlines that there are insufficient sources of funding to support businesses for the long time span that is required until commercialisation is achieved, which is matched by an impatience from government, which does not create a supportive environment for commercialisation. Molapisi (2019) also notes that the structure of the NSI does not fully support commercialisation, as incentives are misdirected towards outputs like publications rather than towards innovation and commercialisation activities. In addition, the state of the current economy could also contribute partly towards the issues in finding commercialisation partners. Some criticism is also levelled at how the impact of a multidisciplinary science like nanotechnology, being "multipurpose and enabling", can be identified, as its exact contribution is not always immediately clear (Saidi & Douglas, 2017: 1).[75] Saidi and Douglas (2017) further suggest that industry may hide the contribution of nanotechnology to their products to avoid any concerns raised about the health and safety aspects of the technology.

[73] Pouris A, Pouris A & Buys A. 2012. *Nanotechnology and Biotechnology Research in South Africa: Technology Management Lessons from a Developing Country.* Proceedings of PICMET '12: Technology Management for Emerging Technologies.
[74] Maruping P. 2019. Interview by M Ward, 26 June 2019.
[75] Saidi T & Douglas TS. 2017. Nanotechnology in South Africa: Challenges in evaluating the impact on development. *South African Journal of Science, 113(7/8): 1-2.*

CHAPTER 5

THE GRAND CHALLENGES

5.1 Introduction

A novel aspect of the TYIP was the introduction of five so-called 'grand challenges'. The stated purpose of introducing these grand challenges as a conceptual framework is that they "address an array of social, economic, political, scientific, and technological benefits" and "are designed to stimulate multidisciplinary thinking and to challenge our country's researchers to answer existing questions, create new disciplines and develop new technologies" (DST, 2008: viii). Each of the grand challenges is outlined in a narrative, the details and scope of which vary quite widely, but in each case a set of "outcomes" is been presented, which are either quantifiable or categorical (i.e. they are either achieved or not).

In a recent article, Tim Flink and David Kaldewey[76] trace the origins and development of the notion of a 'grand challenge' in recent science policy debates. In this discussion, they compare and contrast the 'grand challenges' concept with another concept 'frontier research,' which also became prominent in European Union science and innovation policies in the early 2000s. This trend would only change with the establishment of the European Research Council in 2007 and the inclusion of the notion of frontier research in Framework Programme 7. The following Framework Programme 8 ("Horizon 2020") introduced yet another new programme, and another semantic innovation: the 'societal challenges' rationale. According to the Commission, this reflects a changing of policy priorities to address "major concerns shared by citizens in Europe and elsewhere. The term 'societal challenges' is used mostly synonymously with 'grand challenges', which was first introduced in 2007/08 as a new rationale to justify comprehensive coordination efforts within the promised European Research Area.

The uptake of the notion of grand challenges in the TYIP was quick and became the 'grand narrative' of the plan.

5.2 The Bio-economy Grand Challenge

5.2.1 Context, overview and strategic objectives

The National Biotechnology Strategy which was adopted in 2001 was one of the first policies seen as necessary for the development of the NSI. The NRDS acknowledged this situation and identified biotechnology as one of its key technology missions.

In 2003 and 2007, the DST commissioned two studies[77] to undertake an audit of the South African biotechnology sector.

[76] Flink T & Kaldewey D. 2018. The new production of legitimacy: STI policy discourses beyond the contract metaphor. Research Policy, 47: 14-22.

[77] eGgoliBio. 2004. National Biotech Survey 2003. Modderfontein: eGoliBio Life Sciences Incubator; DST. 2007. *National Biotechnology Audit 2007: Biotechnology use and development in South Africa.* Pretoria: Department of Science and Technology.

In the 2008 TYIP, the 'Farmer to Pharma' Grand Challenge built on the biotechnology mission of the NRDS. Under this particular grand challenge, South Africa would become one of the top 10 emerging economies in the global pharmaceutical, nutraceutical, flavour, fragrance and biopesticide industries, based on innovative use of South Africa's indigenous knowledge and rich biodiversity (DST, 2008: 11).

In 2013, the DST published the Bio-economy Strategy, which replaced the 2001 Biotechnology Strategy. The aim of the Bio-economy Strategy is to promote bio-innovation which, in turn, is expected to generate sustainable economic, social and environmental development, and make a significant contribution to South Africa's GDP by 2050. The strategy identified agriculture, health, and industry and the environment, as the economic sectors "as being the most in need of, and likely to benefit from a comprehensive bio-economy strategy" (DST, 2013: 12). The strategy provides "a high-level framework to guide biosciences research and innovation investments, as well as decision-making as South Africa adapts to the realities of global transition to a low-carbon economy" (ibid.: 3). It also focuses on the coordination of numerous government departments, R&D agencies, the private sector, public programmes and funding bodies to achieve its goals. The overarching strategic objective linked to each of the three sectors is highlighted in the table below. Strategic interventions and associated activities for each objective are outlined in the strategy document.

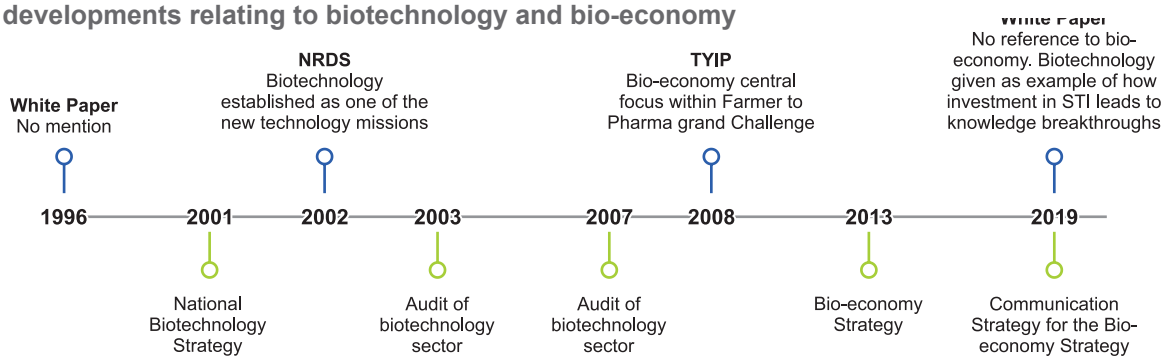
Bio-economy Strategy strategic objectives

Mission	To promote bio-innovation which in turn is expected to generate sustainable economic, social and environmental development	
Strategic objectives	1	Agriculture: Strengthen agricultural biosciences innovation to ensure food security, enhance nutrition and improve health, and enable job creation through expansion and intensification of sustainable agricultural production and processing
	2	Health: Support and strengthen the country's local research, development and innovation (RDI) capabilities to manufacture active pharmaceutical ingredients, vaccines, biopharmaceuticals, diagnostics and medical devices to address the disease burden while ensuring security of supply of essential therapeutics and prophylactics
	3	Industry and environment: Prioritise and support RDI in biological processes for the production of goods and services, while enhancing water and waste to support the green economy

In 2019, the DST produced a Communication Strategy for the Bio-economy Strategy. A document entitled 'Implementation Framework: Bio-economy' has also been developed but had not been approved for release by the DSI at the time of the review.

The key developments relating to biotechnology and bio-economy are captured below.

Key developments relating to biotechnology and bio-economy



5.2.2 Assessments

Our assessment of the strategy design is provided below.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy?		Yes. The Bio-economy Strategy highlights challenges facing the three sectors identified as focus areas of the strategy (DST, 2013: 13): • The importance of agriculture for ensuring food security and job creation, and the role of biotechnology in addressing the challenges of "climate change, diminishing water and grazing land, and potential loss of biodiversity." • The burden of disease and its impact on South Africa's health system, and the country's efforts to address its Millennium Development Goals (particularly eradicating poverty and hunger, and reducing child mortality). • The emerging industrial bio-economy is expected to improve South Africa's competitiveness in respect of the manufacturing sector's energy intensity, water usage, waste management and greenhouse gas emissions. These enhancements will improve the industry's competitiveness and reduce its environmental footprint.
Are the goals and objectives clear and unambiguously formulated?		Yes.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		Yes. There are detailed interventions and associated activities linked to each strategic objective. In each case, both lead and supporting partners are identified and their roles clearly specified.
Is a budget for the interventions provided?		The strategy notes that the proposed interventions would require additional resources. As such, it refers to a Bio-Innovation Venture Capital Fund that "will be established and managed as a public-private partnership, both as a way to attract private capital and to provide an exit mechanism for investors" (DST, 2013: 20). It states: "It is estimated that the fund will require R2 billion, of which the government should supply R300 million to R400 million (15% to 20%) over three years, with investors contributing the remainder." It anticipates that TIA, "in partnership with the Industrial Development Corporation, will play a key role in facilitating a venture capital fund by using government funds to attract private capital" (ibid.). Additional funds would need to be leveraged through private-sector funding (national and international) and philanthropic partnerships.
Are targets and milestones included?		There are no targets or milestones linked to the strategic objectives.
Are intervention outputs clearly specified?		Yes; strategic interventions related to the three focus areas are for the most part specific, and measurable outputs are stated.

Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		Reference is made to impact outcomes under the proposed interventions and activities for each of the three focus areas (agriculture, health, industry and environment). No distinction made between short- and medium-term.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		Indicators of impact outcomes are listed for each of the three focus areas. These are clear and measurable.

Assessment of the implementation of the interventions and associated activities for each strategic objective is provided in the tables below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation of strategic objectives relating to agriculture

Interventions	Activity		Comments	Evidence
Establish a coordinating committee to advise, guide and monitor agricultural innovation	A committee comprising key representatives of government, industry and academia should be established to guide agro-innovation. The committee would prioritise resource allocation, monitor R&D progress, and recommend initiatives to enhance and develop the sector within the scope of the DST's implementation plan.		A coordinating committee was initially established and the implementation plan finalised, with the development of an instrument for the implementation of the Agricultural Bio-economy, viz. the agricultural bio-economy innovation partnership programme implemented by the TIA. The steering committee, Terms of Reference and Standard Operating Procedures (SOPs) enhance oversight over the Agricultural Bio-innovation Partnership Programme (ABIPP)	ABIPP instrument in DSI APP. TORs for steering committee and ABIPP SOPs
Establish a network of agro-innovation hubs that enhance technology transfer and extension	The skills and solutions that emerge from biotechnology research need to be effectively transferred to emerging, small-scale and commercial farmers. Regional agro-innovation hubs can act as catalysts for the collective enhancement of production, agro-processing and marketing by farmers, scientists and innovators.		DST completed the feasibility study on the agro-innovation hubs in 2016. The report was approved by EXCO for implementation but that DST would only implement one or two such hubs in conjunction with rural development. The DDG:TI met with DDG: Rural development Agri-parks and the DDGs resolved that DST would not implement new Agri-hubs but support the ones developed by DRDLR. Despite many analyses of business plans etc. this joint effort never materialised.	Agri-parks programmes as per the co-funded Grain and Oilseeds Innovation Partnerships programme. Co-funded soybean food and nutrition programmes.

Interventions	Activity		Comments	Evidence
			The DST continued its efforts in terms of innovation support for Agri-parks in the form of innovation demonstration projects with industry farmer development support programmes. This included innovation support (smallholder threshing capability and storage) and food and nutrition (nixtamalisation training), diversification of diets (planting beans) and soy processing in communities (yoghurt, milk, snacks). Stellenbosch University adopted the idea of an agro-hub next to the wheat breeding platform which was established.	KPIs – numerous communities benefiting from innovation support and food and nutrition projects.
Crop/livestock improvement both for biotic and physical stresses associated with climate change (including indigenous crops)	R&D programmes need to focus on the commercial sector and on indigenous crops/ livestock to develop traits appropriate to emerging and subsistence farmers.		• Crop improvement: Wheat breeding Platform – a multi-partnership, industry co-funded programme focussing on pre-breeding research to complement breeding programmes and provide cultivars for increased yield and ultimately food security for all farmers. • Crop Protection Consortium – looking at soil borne and seed borne diseases in soybean and maize as well as monitoring of fall army worm. • Climate Change Resilience Consortium (includes maize breeding programmes targeted at smallholder farmers, agro-ecology and other research to look at climate change adaptation). • Animal improvement: Beef breeding and reproductive technologies platform – TIA funded. • Aquaculture Bio-innovation programme supported, and call for proposals (six projects funded in 2019/20).	
Agro-processing initiatives	There are significant opportunities for agro-processing to add value to agricultural produce, and enabling mechanisms should be devised to expand agro-processing innovations and establish small and medium enterprises that improve the quality of South African agro-produce.		Agricultural Bio-innovation agro-processing initiative. Feasibility study completed. Support for Marula and honey-bush value chains. Bid awarded for sorghum feasibility study. Thus far communities supported with Marula trees (with a view to building the value chain) and new improved processing technology supported to support 10 new honey-bush communities.	Marula project supported and co-funded by TIA and IDC. Honey-bush project supported. Sorghum bid awarded.

Interventions	Activity		Comments	Evidence
An integrated food nutrition research programme	The government needs to partner with universities, science councils, the private sector and civil society to promote research into the nutritional composition of food and the detection and elimination of contaminants.		As part of innovation support for Agri-parks, the DST supported innovation demonstration projects with industry farmer development support programmes. This included innovation support (smallholder threshing capability and storage) and food and nutrition (nixtamalization training), diversification of diets (planting beans), and soy processing in communities (yoghurt, milk, snacks).	Currently part of ABIPP – the steering committee has now resolved to develop an integrated food and nutrition portfolio and a concept note was presented to the ABIPP steering committee in this regard. Agri-parks programmes as per the co-funded Grain and Oilseeds Innovation Partnerships programme. Co-funded soybean food and nutrition programmes. KPIs – numerous communities benefiting from innovation support and food and nutrition projects.

Interventions	Activity		Comments	Evidence
Animal vaccine capabilities	Local research and biotechnology institutions have the capability to develop vaccines and diagnostic kits to mitigate the risk of potentially devastating outbreaks of livestock diseases. World-class platforms have been established to support R&D (at Onderstepoort Veterinary Institute) and the manufacture of animal vaccines (at Onderstepoort Biological Products). However, further investment is required to build human capital and critical infrastructure to reinvigorate this sector.		Animal Health Technology Innovation Partnership programme. Various projects supported and a few selected for phase 2 for the next step in terms of commercialisation (gains on e.g. rift valley fever and African horse-sickness; and tick vaccine pre-commercialisation advanced).	
Energy-crop initiatives	The ARC and other relevant stakeholders need to consolidate and enhance their R&D in this field, as significant developments in science, technology and engineering are still required to enable cost-effective conversion to biofuels. Clear linkages should be maintained with the industrial biotechnology initiatives			
Biocontrol and bio-fertilisers	National Biotechnology Strategy supported a number of small, dedicated biotechnology firms that commercialised biocontrol products such as biopesticides, plant-growth regulators and biofertilisers. Programmes to enhance commercialisation of technologies should be developed.		There are a number of TIA and ARC initiatives that are already supported.	TIA Bio-economy work plan – Nemabio biopesticides; ARC biofertilisers.
Aquaculture	Aquaculture promises a cost-effective means of providing a sustainable protein source. This emerging sector in South Africa has a strong need for research, development and commercialisation to help establish it as a sustainable and growing component of the broader agricultural sector.		Aquaculture Bio-innovation programme supported (six projects funded in 2019/20) – part of ABIPP.	Aquaculture bio-innovation programme call for proposals.

Interventions	Activity		Comments	Evidence
Soil conservation	Soil conservation is critical to the sustainability of agriculture. Investment is required to ensure that soil conservation and optimal practices are researched and implemented by commercial and emerging farmers.		The crop protection programme and climate change resilience programmes, and farmer development support programmes, focus on conservation agriculture and how to enrich soils and reduce inputs through rotation of crops and with animals also the effects of temp and elevated CO2 on soil.	
Water resource management	Agriculture uses a significant portion of available water in South Africa. In order to intensify agriculture to address food security and job creation objectives, research into the optimal management practices for irrigation and recycling should be supported.		In context of heat stress and drought tolerance and the differences for irrigated and non-irrigated cultivars, these are covered in the current programmes that focus on climate change resilience; breeding programmes; and smart and precision agriculture – precision planting and phenotyping and decision support. The precision agriculture objectives in the next decadal plan will assist to advance this.	
Build high-value skills and capacities to enable agro-innovation	The creation of an incentive system to promote key skills, including plant-breeding, agronomics, plant physiology and biometry in tertiary-level agricultural education is critical.		On average 10 agricultural postgraduate students supported per year (last five years) and 50 per year since 2016 (inter-programme bursary fund), that includes black and female students. Two NGAP posts for scarce skills (breeding) secured (Stellenbosch University). One already filled by a black female.	Annual reports. Inter-programme bursary fund.
Co-funding initiatives for innovation	The agricultural sector is well-established and values the importance of R&D in order to maintain a competitive edge. Industry-relevant research and capacity development will be supported and stimulated through programmatic co-funding initiatives between industry bodies and government.		At least four public-private partnership programmes; co-funding from GrainSA, Winter Cereal Trust, Maize trust, Sasol Trust, Oilseeds and Protein Oilseeds Research Trust (OPOT), TIA together with DSI.	Other Partners Sensako, ARC, Pannar, various universities, DALRRD, the dti, WCPDoA, NAQUARF.

Assessment of implementation of strategic objectives relating to health

Interventions	Activities		Comments	Evidence
Develop improved therapeutics and drug delivery systems to address priority diseases	Specific priority diseases will be identified in line with the Department of Health's programme of action and in terms of how they affect the Southern African Development Community region. Virtual networks will be created and strengthened to ensure that the capabilities of institutions are harnessed and expanded. The full value chain for drug design will be addressed, from discovery to new delivery systems (including nanoparticles), while the necessary infrastructure, such as preclinical testing facilities, will be established.		Value chain analysis completed Various malaria candidate drugs developed through the H2D platform that was created Funding for drug development made available via SAMRC Strategic Health Innovation Partnership Preclinical drug development platform established with various animal models Phase I – III clinical research facilities established Co-fund various clinical research studies	http://www.h3d.uct.ac.za/ http://health-sciences.nwu.ac.za/pcddp Various SHIP reports http://www.crc.uct.ac.za/
Develop new and improved vaccines and biologics	South Africa's vaccine development and biomarker expertise, especially in HIV and TB vaccines, should be strengthened by establishing networks. Given the increase in chronic diseases and the opportunities for technology transfer and knowledge pools, a private-public partnership to develop therapeutic biologics needs to be considered. Investments in the emerging global biosimilars industry will allow South Africa to skip several stages of development.		Part owner of the Biovac Institute Various research studies funded via SHIP and SAMRC Afrigen Bio company created with IDC funding Funding of projects via TIA	https://www.biovac.co.za/ Various SHIP reports TIA investment reports
Develop improved diagnostics	Robust, rapid diagnostics are needed particularly in resource-poor areas to enable healthcare providers to diagnose HIV, TB and other high-burden diseases at the point of care. Regular testing of these diseases is essential, which has created an opportunity to build this industry further. Government has helped establish a number of companies involved in the manufacturing of diagnostics. In addition, a number of research institutions are developing improved diagnostics. A more concerted and coordinated effort is needed to strengthen capabilities and expertise.		Funded the development of various diagnostics for HIV, TB and diabetes Funding of genetic-based diagnostics and precision medicine programme The buy-in for the DoH is problematic	Various SHIP reports

Interventions	Activities		Comments	Evidence
Develop improved medical devices	A large portion of South Africa's medical-device innovation occurs in established private firms (bearing in mind that between 80% and 90% of products consumed in South Africa are imported). This innovation generally falls within the existing products and services that the business provides, and addresses a recognised market need. South Africa has a strong history of developing medical devices, such as the CAT scan. Innovations in this field need to be further developed.		Medical Device and Diagnostic Cluster being established. Various medical devices developed through funding from TIA and SHIP.	
Strengthen clinical R&D capabilities	Owing to South Africa's disease profile, multinational companies and international clinical research organisations conduct local clinical developments using South African candidates. However, they do this without building local capabilities. To develop its therapeutics, the country needs to revitalise its clinical research, curtail high costs and enable commercialisation.		ASSAf report assessing this intervention completed. Phase I – III clinical research sites being supported. SAMRC driving the initiative.	Various SHIP reports SAMRC annual reports
Establish pharmaceutical manufacturing	South Africa needs to grow a pharmaceutical manufacturing sector. This will include the local manufacturing of generic and new drugs, and establishing facilities to encourage the industrial development of biologics and diagnostics. The Department of Science and Innovation will create the necessary enabling environment for local manufacturing in partnership with other departments such as Trade and Industry and Economic Development, and Health. Specific technology parks to help achieve this objective will be supported.		Ketlaphela was established but the control is now resting with NECSA. API Cluster document finalised and will be launched in January 2020. CPT API Pilot plant established.	http://www.ketlaphela.co.za/ https://sites.google.com/chemprotech.co.za/home/cpt-pharma API document can be made available

Assessment of implementation of strategic objectives relating to industry and environment

Interventions	Activities		Comments	Evidence
Strategic industrial biotechnology programmes	Strategic science programmes need to be initiated so that industry-relevant products can be developed to enhance production efficiency, product quality and the industry's competitiveness. These programmes should build on existing initiatives such as biopharming, bio-catalysis, bio-composites and mineral leaching. The key RDI areas that will stimulate the industrial bio-economy are microbial strain development for important bio-based chemicals, host expression systems for enzyme production, fermentation technologies (solid state and submerged), bioprospecting, genetic and metabolic engineering, high throughput biology, bioinformatics and downstream recovery processes. The industrial bio-economy sector will benefit from other national priorities, such as healthcare and food security.		In 2018, industry and environment launched a bio-innovation programme (SIIP) as an instrument to facilitate biopharming, bio catalysis, bio composites and material leaching. The key RDI areas that will stimulate the industrial bio-economy are microbial strain development values chains, comprising basic and applied research as well as technology translation and commercialisations actions industrial bio-economy sector.	
Strengthen and develop bioprospecting capacity and capabilities	As large-scale biomanufacturing activity in South Africa is currently very limited, inward technology transfer from international companies and research groups, as well as supporting development initiatives that adapt such technologies for local use may be necessary. Sustainable bioprospecting for unique industrial biocatalysts for application in any of a number of bioprocesses may be an area for initial focus. Areas of possible application include the chemical and pharmaceutical industries and bio-refineries where biocatalysts can potentially green the processes by replacing synthetic catalysts to give both economic and environmental benefits.		DSI funded the National Biocatalysis Initiative aimed at providing the opportunity to develop and implement manufacturing technologies in the chemical industry that are more cost-effective and have less environmental impact.	DSI-CSIR contract, tech transfer agreement and product prototypes generated
Strengthen local bioprocessing capabilities	Collaboration and partnerships between industry and academia that can address competence hurdles and knowledge spill-overs, and alleviate the risks of transforming knowledge into commercial products, must be encouraged and will be supported.			

Interventions	Activities		Comments	Evidence
Develop integrated biorefineries from bio-based feedstocks	An industrial bio-economy should develop an integrated bio-refinery concept for the co-production of food and non-food (feed, chemicals, materials and energy) to facilitate the transition from fossil resources to renewable bio-resources. An integrated bio-refinery will provide cost and energy-efficient ways to make optimal use of biomass for several purposes. Biomass could be used as building blocks for the generation of high-value products such as proteins, fine chemicals, carbohydrates and oils, which create opportunities for a viable industrial bio-economy.		The DST-funded the Bio-refinery Research value chain for the development of a new value chain from biomass.	DSI-CSIR consortium and consortium research collaboration
Strengthen wastewater research, development and innovation	The country has world-class expertise in wastewater research at universities, research councils and large industrial players. The DSI will facilitate collaboration to generate knowledge, prevent duplication of work and enhance value addition. Pilot and demonstration-scale wastewater treatment facilities need to be developed to test and market larger-scale treatment facilities. Additionally, innovation in water pollution needs to include focus on bioassays and biomarkers.		DST funded Bioremediation research consortium. The initiative is composed of researchers from South African universities (UNISA, UJ, UNIVEN and CPUT). All researchers are working in the field of water bioremediation research, with the aim of treating various wastewater from domestic to industrial sources. The major aim is to develop an artificial / constructed wetland system that is capable of treating such wastewater to acceptable levels according to the National Water Act (1988) of South Africa before disposing to water bodies.	
Strengthen solid waste research, development and innovation	Economic development has contributed to an increase in industrial, mining and power-generation waste. Electronic waste is also starting to accumulate in landfill sites. The following biological applications aim to minimise waste generation and create an effective waste-management system: • Closed-loop system of environmental application using microorganisms. • Harvesting landfill gas for heating, electricity and as an alternative fuel source. • Beneficiation of biomass waste for energy recovery and generation (waste to energy). • Alternative use of wastewater streams for other products.			

Interventions	Activities		Comments	Evidence
	• Electronic waste needs to be reused and recycled, and its relevant components recovered. • Metals from electronic waste can be recovered by combining hydrometallurgical (chemical) processes and bioprocesses (bio metallurgy, bioleaching and biosorption).		Did not happen due to limited resources.	
Synergies with enabling and emerging technologies	The industrial bio-economy needs to synergise with converging research in order to unlock opportunities (which include areas of synthetic and structural biology, functional genomics and nanotechnology). Furthermore, untapped areas such as marine biotechnology can be beneficially harnessed.		Did not happen due to limited resources.	
Establish an advisory committee for industrial bio-economy	A stakeholder advisory committee will be established to guide and monitor the industrial/environmental aspect of the Bio-economy Strategy.			

The Bio-economy Strategy identified agriculture, health, and industry and the environment, as the key economic sectors that would benefit most from its implementation.

Implementation of the interventions relating to strengthening agricultural biosciences innovation has, overall, been positive. The proposed coordinating committee has been established; and various R&D platforms and consortia for crop/livestock improvement, agro-processing initiatives, and programmes for animal vaccines, are in place. Good progress has been made towards building high-value skills and capacities to enable agro-innovation, as well as the development of co-funding initiatives to support innovation. Partial progress has been made in the establishment of a network of agro-innovation hubs, an integrated food nutrition programme, and initiatives relating to biocontrol and bio-fertilisers, aquaculture and soil conservation. Assessments could not be made in relation to energy-crop initiatives and water resource management.

Far less progress has been made towards the achievement of the health-related interventions, where only one of the activities – the development of improved therapeutics and drug delivery systems to address priority diseases – has been achieved. Only partial progress has been made in relation to all the other intervention activities (developing new and improved vaccines and biologics, developing improved diagnostics and medical devices, strengthening clinical R&D capabilities, and establishing pharmaceutical manufacturing).

Finally, with regard to the industry and environment strategic objective, five of the eight interventions have been undertaken, namely those relating to establishing strategic industrial biotechnology programmes, strengthening and developing bioprospecting capacity and capabilities, strengthening local bioprocessing capabilities, developing integrated bio-refineries from bio-based feedstocks, and strengthening wastewater RDI. Only some progress has been made towards the establishment of an advisory committee for industrial bio-economy. The intentions to strengthen solid waste RDI, and to create synergies between industry and emerging technologies, have not been achieved – in both cases owing to limited resources.

5.3 The Space Science and Technology Grand Challenge

5.3.1 Context, overview and strategic objectives

The 1996 White Paper on S&T was largely silent on 'space science' as a distinct activity, blending this into the radio-astronomy and telemetry role of the Hartebeesthoek Radioastronomical Observatory (HartRAO). In the NRDS, space science is subsumed under ICT as one of the new technology platforms, although its goal statements do not define 'space science' as such. One NRDS goal was to explore the South Atlantic Magnetic Anomaly (geomagnetism and space science); a second to continue prior knowledge advantage in microsatellite engineering.

The TYIP introduced the Space Science and Technology Grand Challenge whereby "South Africa should become a key contributor to global space science and technology, with a National Space Agency, a growing satellite industry, and a range of innovations in space sciences, earth observation, communications, navigation and engineering" (DST, 2008: viii).

These intents then gave rise to the South African National Space Agency Act No. 36 of 2008. In 2009, the dti published its National Space Policy which, among others, reiterated the cooperative governance to be applied to space matters as well as the lead role of the DST for the national space programme. The commissioning of the South African National Space Agency (SANSA) took place in 2010. In the same year, the DST published the National Space Strategy (NSS). The vision for space S&T in the NSS is described as follows (DST, 2010: 4):

> *Space science and technology will be used as a platform to provide essential data and services to a wide array of applications ranging from research and development to commercial services. In addition, space science and technology will be used as a tool to monitor and evaluate critical resources in our terrestrial landscape that is deemed important for decision making and which lends support to sustainable socio-economic development.*

The NSS identifies three priority areas, each of which contains key areas of intervention. The priority areas are: (1) environment and resource management; (2) health, safety and security; and (3) innovation and economic growth. The NSS considers these priority areas to collectively represent the national priorities of the country which will form the central focus of the national space programme. In order to deliver on the key priorities highlighted above, four thematic areas were identified: (1) earth observation, (2) satellite communications, (3)

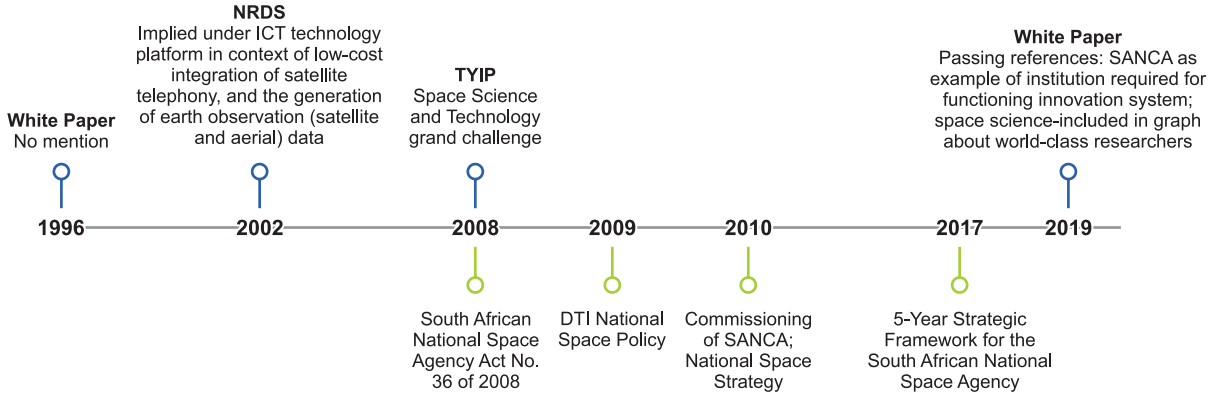
navigation and positioning, and (4) space exploration. Under each of the thematic areas a number of expected deliverables are identified, which form the bedrock and focus of the national space programme. The strategic objectives of the NSS are outlined in the table below. The strategy lists three supporting platforms critical for the realisation of the programmatic functions and objectives: (1) human capital, (2) infrastructure, (3) and international partnerships.

Space science and technology strategic objectives as per the National Space Strategy

Mission	To provide for the promotion and use of space and co-operation in space-related activities, foster research in space science, advance scientific engineering through human capital, and support the creation of an environment conducive to industrial development in space technologies	
Strategic objectives	1	Develop the local private space S&T industry sector
	2	Develop services and products that can respond to user needs
	3	Develop an export market for specific equipment for satellite or services offered from existing facilities
	4	Organise some of the current space S&T activities into strategic programmes
	5	Optimise the organisation of future space activities to respond to opportunities with international industrial partners or international space agencies
	6	Partnerships with established and developing spacefaring countries for industrial and capacity development purposes
	7	Strengthen training and technology transfer programmes, including the sharing of experience and expertise
	8	Promote space S&T in academic institutions and science centres and the provision of opportunities for both short-term and long-term training and education
	9	Respond to challenges and opportunities in Africa
	10	Advocate the importance of space S&T as a priority measure for meeting national development needs
	11	Build local awareness of space S&T and its benefits

Key developments relating to space S&T are highlighted below.

Key developments relating to space science and technology



5.3.2 Assessments

Our assessment of the strategy design is provided below.

Well addressed

Moderately well addressed

Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy?		Yes. Included in the strategy is a SWOT analysis, which identifies some of the weaknesses and threats facing the space sector. Similarly, SANSA, in its Strategic Framework, identifies threats and weaknesses facing the space sector.
Are the goals and objectives clear and unambiguously formulated?		The NSS sets out to develop a space programme that: helps South Africa to understand and protect the environment, and develop its resources in a sustainable manner; strengthens developmental efforts through ensuring the health, safety and security of South Africa's communities; and stimulates innovation, while leading to increased productivity and economic growth through commercialisation. This vision is exceptionally broad, and as such might be beyond attainment by a single strategy. The strategy also identifies key priority areas, thematic programmes, strategic objectives and functional programmes. The strategy thus reads as incoherent without clear objectives.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		The strategic objectives outlined in the NSS are broad without specific interventions or activities stated. Accordingly, the NSS does not make mention of the agencies or partners to implement the objectives.
Is a budget for the interventions provided?		The NSS does not include any budgetary allocations or financial implications related to the implementation of its goals.
Are targets and milestones included?		Aside from the proposed implementation plan (which will have a 10-year timeframe) the NSS does not identify any milestones or timeframes associated with the implementation of objectives.
Are intervention outputs clearly specified?		The NSS does not clearly specify intervention outputs.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		To a certain extent. Although the strategic objectives of the NSS are broad and vague, the strategy does include expected deliverables within thematic areas which are clearly specified. No distinction made is made between short-term and medium-term outcomes. The NSS does not provide any timelines associated with its goals and outcomes.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		The NSS does include a proposed indicator framework and some possible indicators. However, these indicators cannot readily be used against which to assess progress. Only one of the indicators/targets explicitly align with the strategic objectives/key deliverables outlined in the strategy.

Assessment of implementation is provided in the tables below. Given the broad and largely unmeasurable nature of the strategic objectives of the NSS, we cannot assess progress towards their implementation. Instead, in the first table we assess progress towards the expected deliverables as identified under the four thematic areas which support implementation of the three key priority areas identified in the strategy. This is followed by an assessment of some of the more general interventions outlined in the policy documents.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of progress against the expected deliverables of the NSS

Deliverable		Comments	Evidence
Establish an earth observation data centre		The Earth Observation Data Centre was established under the CSIR. SANSA, in its Strategic Framework (2020-2025) aims to position the EODC as a "central hub for earth observation data archiving, storage and dissemination of data and information on the African continent. This will be achieved through implementing a High-Performance Computing Centre for earth observation enabled for Big Data processing and with the capacity to provide cloud services. The cloud solutions will enable better scalability, as new sensor data requirements emerge".	SANSA (2017: 36)
Develop a platform to integrate satellite and in-situ data		The SANSA Strategic Framework identified one of its objectives to improve the infrastructure requirements around satellite data: "Currently there exists an extensive ground-based network providing data on the space environment over South Africa. This needs to be expanded to widen the observable area into Africa. The research infrastructure requirements include distributed ground networks, access to satellite data, and high-performance computing requirements. The aim is to build on the existing infrastructure, stretch the capacity to include satellite data from the African region, and build on the existing computational capacity. Expansion would include the introduction of African ionosondes, and GPS scintillation receivers strategically placed in the north to supplement the existing network, an optical scanning Doppler imager in Sutherland, and a LOFAR station in Hermanus. Long term plans include a low-latitude radar located in South Africa. The opportunities for hosting infrastructure for national and international partners will be explored with the view to becoming a strategic hosting partner in the future. This will entail utilising SANSA expertise, and regional partners to broker locations and commissioning of hosted infrastructure for stakeholders in space science. For example, the hosting of equipment for the Satellite Based Augmentation System (SBAS) project, and the hosting of a European GPS receiver in Zambia".	SANSA (2017)
Develop medium to high resolution payloads		Ultimately, South Africa must provide the full space mission life-cycle capabilities for the development and operations of optical, SAR and scientific payloads. These capabilities must include the design, modelling, development, measurement, calibration, test and evaluation of technology options. This will make South Africa an attractive partner for human capital development, while ensuring a sustainable payload and full satellite development programme. On the payload side, there are many opportunities arising where South Africa is able to provide specific payloads hosted on foreign satellite missions. This will alleviate the full cost of a satellite mission, but yet still deliver useful data. Additionally, the development of a navigation payload strategy is considered a critical activity to be completed.	SANSA (2017: 54) (ibid.: 58)

Deliverable		Comments	Evidence
Establish centres of competence for optronics and synthetic aperture radar		In 2010, the DST planned to establish centres of competence (CoC) in Aptronics and synthetic aperture radar to support South Africa's future space programme. In 2010, South Africa had an existing CoC for optronics in the CSIR, also an agency of the DST. Research and Development was also conducted at Carl Zeiss Optronics (CZO) in Centurion. CZO is 30% owned by state arsenal Denel. In 2015, the DST launched the Synthetic Aperture Radar (SAR) initiative as a CoC.	https://www.defenceweb.co.za/joint/science-a-defence-technology/dst-moots-centres-of-competence-in-optronics-and-synthetic-aperture-radar/ CSIR (2017)[78]
Develop the African Resource and Environmental Management Constellation in partnership with other African countries		The African Resource Management Constellation (ARMC), a collaboration which involved Nigeria, South Africa Kenya, and Algeria. Initially conceived around 2004, when it was named the African Resource and Environmental Management Satellite Constellation, the initiative was meant to develop a constellation of satellites to provide real time, unrestricted and affordable access to satellite data to support effective environmental and resource management in Africa. The space agreement on the African Resources Management Satellite Constellation (ARMC), which is a Memorandum of Understanding between the partners, was signed by the governments of the four countries on the 7th of December 2009 during the Third African Leadership Conference on Space Science and Technology for Sustainable Development that held in Algiers, Algeria.	https://iinitiative.wordpress.com/2009/12/21/african-resource-management-satellite/
Consolidate the acquisition of space data for government			
Develop technologies for low data rate payloads		The development of a navigation payload strategy is considered a critical activity to be completed. SANSA reported in its Strategic framework (2017) that it has produced one successful science payload in 2020/21 but that it aims to provide an environment conducive to innovation in the quest to develop low cost science payloads for satellite missions.	SANSA (2017: 44,58)
Develop technologies for applications in e-education, telemedicine and rural communication and disaster support		SANSA (2017) reported that between 2018/2019 and 2022/23 it would have developed 13 e-education applications. These applications will ensure access to high-quality education, especially to rural communities that have been marginalised to date.	SANSA (2017: 67)

[78] CSIR. 2017. *Research Design and Implementation Requirements: Centres of competence research project.* Pretoria: Council for Scientific and Industrial Research.

Deliverable		Comments	Evidence
Develop a geostationary (GEO) communications system		SANSA reported in its Strategic Framework (2017) that the South African position with regards to geostationary communications satellite is a little more challenging than that of either optical or SAR platforms. The primary question is whether South Africa should pursue this capability for communications satellites that will be built once every 15 years on average. Unless dictated by market feasibility, some important policy decisions need to be made with respect to whether South Africa should pursue an indigenous industrial capability for communications satellites.	SANSA (2017: 65)
Launch a small GEO satellite		In 2018, it was reported that MzansiSat, which has its origins in the Stellenbosch-based StellSat, wants to launch South Africa's first-ever geo-stationary satellite in a private public partnership that will see the government retaining 20% of the payload for its own security needs. The idea is to create a public private partnership with the state, whereby the state will be receiving 51% of the revenue from the commercial operation while getting autonomy over 20% of the payload for its own use.	https://www.defenceweb.co.za/aerospace/aerospace-aerospace/mzansisat-looks-to-launch-sas-first-geostationary-satellite/
		The NSS does not specify the actors/agencies who should undertake this activity, but from our evidence, this deliverable has not yet been met.	
Develop a navigation augmentation system		SANSA reports (2017) that the Department of Transport (DoT) is responsible for Navigation and Positioning products and services, and the Department of Telecommunications and Postal Services (DTPS) is responsible for Satellite Communications products and services. DTPS, in conjunction with the DST, are currently motivating for a national Telecommunications Satellite, which will have implications for SANSA. A plan for a regional satellite-based augmentation system has been developed by SANSA but will be implemented once the requisite investment is secured.	SANSA (2017: 39)
Develop navigation applications to support user requirements		SANSA (2017) reported that it is currently not servicing its mandate with respect to products and services applications for Navigation and Positioning, and Satellite Communications. There are mainly two reasons for this, namely (i) a lack of funding that does not allow SANSA to service these obligations, and (ii) the responsibility for these thematic areas reside in other government departments, other than the DST.	SANSA (2017: 39)
Grow the knowledge economy through space environment research, and applications development		SANSA acknowledges the centrality of doing research to promote space science in South Africa. As one of their planned activities, they aim to establish an Earth Observations cloud as a node in the African Research Cloud will facilitate enhanced data access services, joint technology development, sharing of distributed infrastructure and involvement in strategic and collaborative data systems research programmes.	SANSA (2017: 36)

Deliverable		Comments	Evidence
		They also anticipate that SANSA researchers and experts will focus on the development of essential base products and services that is needed by the end-users and also by public and private sector entities for use in their respective products and services. The development and distribution of these base products and services will provide an enabling environment for other entities to further pursue business and development opportunities; thus, meeting SANSA's mandate of developing the local space industry. SANSA will also provide essential training, where required, to develop the skills of the Earth observation sector in using the base products and services, thereby increasing the demand for such products and services. The blue assessment of this intervention is given due to a lack of evidence on research output within the space sector.	
Develop joint partnerships in space science payloads		No evidence was found to assess progress towards this deliverable.	
Establish and support centres of competence		Since 2010, four centres of competence were established in Space Science. In the NSS, a target to establish four CoC's by 2017 was set and we therefore consider this deliverable to be achieved. However, we do not know the status of these CoCs today.	https://pmg.org.za/committee-meeting/20104/
Establish and support research chairs		In 2018, there were two active SARChI chairs in Astrophysics and Space Physics (NWU and UCT). However, there are a large number of research chairs in Astronomy.	https://www.nrf.ac.za/division/rcce/instruments/research-chairs

Assessment of the implementation of space S&T strategic objectives

Intervention	Activity		Comments
Establish the National Space Agency	Legislation prepared; organisational design		SANSA operational as of 2010.
A growing satellite industry	Signalling to interested parties		This objective is a qualified success. A modest cluster of satellite/space science-related firms has emerged in the Stellenbosch-Somerset West area of the Western Cape. This area is part of the Southern Node of the telemetry sectoral system of innovation (Kahn, 2014),[79] and includes established (Reunert Radar, EDH), merged and acquired (Sunspace-Spaceteq, and EMSS-Alphawave), and new (SCS Aerospace Group) companies. The universities of Cape Town, Stellenbosch and Cape Peninsula University of Technology with French-backed F'SATI, Denel, and Armscor continue to provide skills and infrastructure.

[79] Kahn M. 2014. *SMEs and the Telemetry System of Innovation*. Paper presented at IAMOT 2014, Washington, 22-26 May 2014.

Intervention	Activity		Comments
A range of innovations in space sciences, earth observation, communications, navigation and engineering	Commercial activities		This objective also records as a qualified success as embodied in the product offerings of these companies and the universities (e.g. Philae lander flywheel of Stellenbosch University). Their turnover is unknown, but far short of the R12 billion suggested in the strategy. Likewise, it is impossible accurately to quantify the human capital stock, but this is probably in the order of the 400 set as an indicator (Alphawave alone had ±100 staff some seven years back). As to patenting, a detailed search is required to separate out the invention and jurisdiction of award. The aggregate total for EDH, Alphawave and EMSS could be as high as 45 awards, well above the target of five.

South African Space S&T, evaluated against its own objectives, and the embedded objectives of the three policy instruments, has made limited gains. Some niche expertise has been retained in telemetry and instrumentation, but there is no evidence of an active launch programme.

In evaluating the National Space Strategy, we find that its objectives are often broad and unclear. The document is lengthy, and the convoluted structure makes the identification of measurable outcomes difficult. However, the NSS does identify key priorities, thematic areas and expected deliverables under these areas. Some of the key deliverables outlined under the thematic areas seem to have been in place at the time that the NSS was drafted. Additionally, its strategic objectives are largely broad and unmeasurable. Accordingly, the NSS does not provide any timelines against which strategic objectives or deliverables should be realised or which agencies should take the lead in implementing some of the proposed activities. The NSS is also very ambitious in its theory of change in that it considers the promotion of space science and the establishment of a national space programme as critical in the promotion of socio-economic development and growth.

Nonetheless, SANSA has made some gains in implementing the strategic objectives and activities outlined under the key priority areas. Even though SANSA is the de facto sole implementing agency of a South African space programme, it faces considerable challenges in fulfilling its mandate – the most significant of which relates to limited funding. In its Strategic Framework, SANSA identifies some of the key challenges facing the space sector (SANSA, 2017: 30-31).

> Currently, SANSA *is fulfilling its obligation in providing Earth observation data, products and services for applications requiring 1m resolution and above. However, this is not accomplished without internal funding challenges, as SANSA is not able to fully cover the costs of providing for these services. This is exacerbated by the fact that there is no effective mechanism in place to recoup costs, thus leaving SANSA with the burden of fully subsidising government from its parliamentary grant for these services.*
>
> *The worrisome aspect is that SANSA is currently not servicing its mandate with respect to products and services applications for Navigation and Positioning, and Satellite Communications. There are mainly two reasons for this, namely (i) a lack of funding that does not allow SANSA to service these obligations, and (ii) the responsibility for these thematic areas reside in other government departments, other than the DST. On the latter point, the Department of Transport (DoT) is responsible for Navigation and Positioning products and services, and the Department of Telecommunications and Postal Services (DTPS) is responsible for Satellite Communications products and services. DTPS, in conjunction with the DST, are currently motivating for a national Telecommunications Satellite, which will have implications for SANSA. A plan for a regional satellite-based augmentation system has been developed by SANSA but will be implemented once the requisite investment is secured.*
>
> *With regards to space exploration, firstly, SANSA Space Science is implementing a number of programmes, but these and the potential of doing more is constrained by the financial reality. Thus, a lot more can be done in this area if more funding was forthcoming. Secondly, there are other areas of space exploration that sit outside of SANSA, a prime example being space geodesy which is critically important for SANSA's business, but sits in the nexus between space science and astronomy. Thirdly, SANSA Space Operations does not receive a parliamentary grant for its operations and is largely reliant on the generation of external revenue, which would constrain the unit from supporting space exploration missions. Hence, in the area of space exploration more can be done if (i) appropriate budgets were allocated and (ii) relevant structural reforms were made to optimise cross-collaboration.*

In summary, to repeat, the main negatives and positives are the limited gains realised. Some niche expertise has been retained in telemetry and instrumentation, but there is no evidence of an active launch programme.

5.4 The Energy Security Grand Challenge

5.4.1 Context, overview and strategic objectives

This review covers the strategies relating to the energy objectives of the NRDS and the TYIP, as well as the DST's 2007 *National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy, 2008 draft Energy Research Development and Innovation Strategy, and 2015 Solar Energy Research, Development and Implementation Roadmap.*

Energy was not a core issue for the NRDS. By contrast, energy (security) is a dedicated grand challenge in the TYIP and there are many references in the document to the energy sector.[80] It is clear from these statements that energy was considered at the time of the TYIP to be central to the strategy of the DST and, more broadly, strategically aligned with other policy initiatives such as the dti's Industrial Policy Action Plan, and that the energy-related goals of the TYIP would be realistically achieved through DST-sponsored R&D. The energy-related objectives of the TYIP are not clearly organised. The high-level strategic objectives of the energy strategy are outlined in the table below. The TYIP does not indicate specific interventions. In the full review (Volume 5: Annexure 19), interventions are extrapolated from a reorganisation of the goals of the energy strategy according to subsector. Thus, for example, strategic objective 1 relates to the need for energy security and the associated interventions relate to non-renewable-based energy generation. Strategic objective 2 also relates to the need for energy security and the interventions centre on renewable energy generation.

High-level goals of the TYIP relating to the energy grand challenge

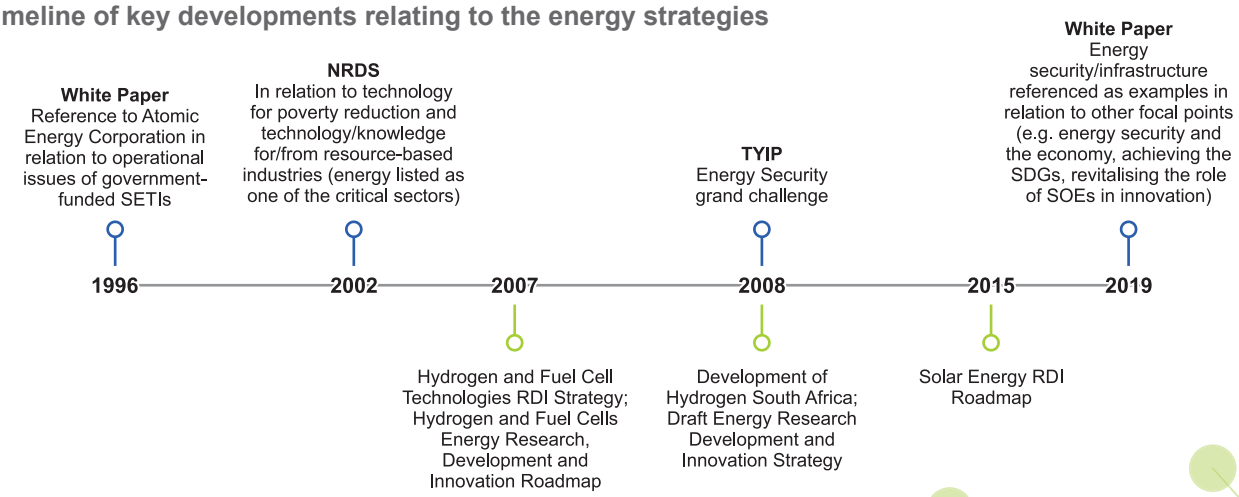
Strategic objectives	1	Ensure the need for energy security as supply and security concerns converge
	2	Protect the environment, particularly given high levels of fossil fuel emissions
	3	Ensure access to affordable, safe, clean and reliable energy

The Hydrogen and Fuel Cell Technologies RDI Strategy was published in 2007. The goals of the strategy are: establishing a base for hydrogen production, storage technologies and processes; establishing a base for developing platinum group metals (PGM)-based catalysts; and building on existing global knowledge and developing know-how to apply and build on existing hydrogen fuel cell technologies for niche applications to address regional developmental challenges. The Hydrogen Strategy was initiated through the 2007 Hydrogen and Fuel Cells Energy RDI Roadmap. This led to the development of the large research project known as Hydrogen South Africa (HySA) in 2008. There are three implementation phases to HySA: the establishment of R&D capability (2008-2013); demonstrating and validating technology (2014-2018); and commercialising South African innovation (2019-2023). The DST's implementation of the energy grand challenge took effect from 2008. Initially, the Department took a diverse approach, funding a range of projects across the energy spectrum. However, by 2018, the portfolio had been deliberately focused into six main areas: The Advanced Biofuels Programme; Hydrogen South Africa; Renewable Energy Hub and Spoke; Energy Efficiency; Energy Storage; and Carbon Capture and Use.

In 2008, the DST drafted the Energy Research Development and Innovation Strategy (ERDIS), which was a component of the TYIP grand challenges but was never formally adopted. The ERDIS was a clear attempt to articulate the role of the DST within the energy sector since the energy strategy of the TYIP represented a confusion of mandates between the DST, the Department of Energy and the Department of Public Enterprises. In 2015, the DST drafted the Solar Energy Research, Development and Implementation Roadmap. Although positioned as a roadmap, most of the core actions relate to the development of the technology rather than the overall sector.

The timeline of these key developments is depicted in the figure below.

Timeline of key developments relating to the energy strategies



[80] All of the actions from the TYIP are broadly referred to in this document as the 'energy strategy' (rather than the energy grand challenge).

5.4.2 Assessments

Our assessment of the energy strategy design is provided below.

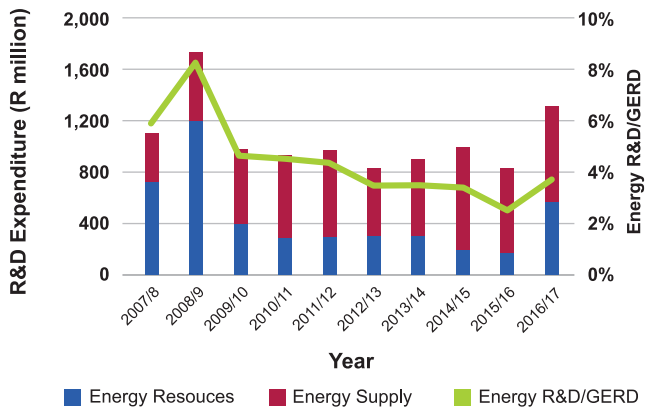
Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of strategy design

Is any reference made to problems or challenges being addressed by the strategy?		Yes; the problem statement for the strategy and the background is well-stated.
Are the goals and objectives clear and unambiguously formulated?		The sub-goals are not aligned with the active programmes and activities, and some of the sub-goals do not link to any one of the three high-level objectives (such as the target that energy should remain heavily coal-dependent). The main issue is the overlap with the mandates of the other actors in the energy sector.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		Taken together, the interventions outlined in the energy strategies are clearly specified. In all cases the DST is the responsible party. However, the extent to which the Department can implement the action, when it remains the objective or mandate of another department, is questionable.
Is a budget for the interventions provided?		No budget is provided in the TYIP.
Are targets and milestones included?		Targets are included in the TYIP but they are either not achievable or beyond the influence of the DSI.
Are intervention outputs clearly specified?		Yes; the outputs are specified. However, many of the outputs are weakly linked to the objectives and in some cases totally irrelevant or even contradictory.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		Overall outcomes for the energy security grand challenge are indicated, to be achieved by 2018. No distinction made between short- and medium-term although all of the targets are comparatively short-term.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		No such indicators are specified.

At the input level, the clearest indicator for the implementation of the TYIP goals would be an increase in energy-related R&D, the data for which has been collected by the National R&D Survey since 2007. As shown in the figure below, apart from an initial spike in 2008/09, such R&D has not changed to any extent in nominal terms, and has decreased in both real terms and as a proportion of GERD. Moreover, the relative contribution to the total energy-related R&D from energy resources and energy supply (presumably raw material and conversion technology, respectively) has fluctuated with no clear pattern.

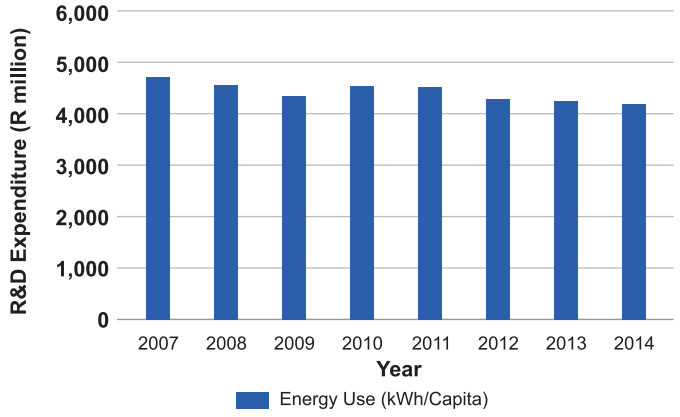
Trends in energy-related R&D (total and as a proportion of GERD) (2007/08-2016/17)



Source: R&D Survey data

On the output side, the per capita energy consumption can be used as an indicator of the trend towards energy-intensive high-value economic activity, and of increasing energy efficiency, where the latter was an explicit goal of the TYIP. As shown in the next figure, energy use per capita has also not changed in the period 2007-2014 (the year for which the latest data is available).

Energy use per capita (2007-2014)



Source: R&D Survey data

Assessment of the energy-related metrics for the energy subsector goals is shown in the table below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of the energy-related metrics

Intervention	Metric		Initial value	Final value
1.1	< 75% of energy used from coal		> 80%	> 80%
1.2	> 30% of energy used based on clean coal technologies		< 5%	< 10% (there is no such thing as clean coal)
1.3	> 50% of new capacity coming from clean coal technologies		< 10%	<10%
1.4	Expanded the knowledge base for building coal plants' parts		N/A	N/A
1.5	Sourced more than 50% of all new energy capacity locally		N/A	N/A
1.6	Nuclear forms 20% of energy used		6%	6%

Intervention	Metric		Initial value	Final value
1.7	Expanded the knowledge base for building nuclear reactors		N/A	N/A
1.8	Sourced more than 50% of all new nuclear capacity locally		N/A	N/A
1.9	Successfully integrated uranium enrichment into the fuel cycle and feeding into the commercial reactors		N/A	N/A
2.1	Renewable energy to form 5% of energy use		3%	9%
2.2	25% share of the global hydrogen infrastructure and fuel cell market with novel PGsts		N/A	N/A
2.3	Demonstrated at pilot-scale the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source		Not available	Technology has been demonstrat-ed through HySA
2.4	A well-articulated energy efficiency programme and per capita energy demand reduced by 30%		4,428 kWh/p	4,200 kWh/p (decrease of 13%)
3.1	Ensure universal access to affordable, safe, clean and reliable energy		83% access; medium cost; highly polluting	86%; high cost; highly polluting

The metrics in the table above have been arranged according to the high-level strategic objectives of the TYIP. The original objectives and the core activities were somewhat difficult to align in this review. The initial objectives and targets related to energy use, diversification of energy sources, and the energy trilemma. However, the core activities have been grouped into HySA, energy efficiency and renewable energy. As a result, the strategic objectives have been re-organised into the three categories of: Non-renewable energy (strategic objective 1); Renewable energy (strategic objective 2); and Energy trilemma (strategic objective 3). The latter two are reflected in the summary scorecard below since the interventions in strategic objective 1 (non-renewable energy) lie outside of the DSI's mandate.

Summary of scorecard for energy strategy

Strategic objective	Intervention	Assessment
2	Renewable energy to form 5% of energy use	
	25% share of the global hydrogen infrastructure and fuel cell market with novel PGM catalysts	
	Demonstrated at pilot-scale the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source	
	A well-articulated energy efficiency programme and per capita energy demand reduced by 30%	
3	Ensure universal access to affordable, safe, clean and reliable energy	

The energy sector is critical to the South African economy and the well-being of its citizens. As a result, the inclusion of energy as a grand challenge within the TYIP was an important step towards ensuring a secure, reliable, affordable and clean energy supply.

Unfortunately, the energy sector has been at the centre of the decline of South Africa's economy. Not only has its main electricity supplier been unable to deliver power to its user base, it has been responsible for many badly managed and expensive projects which have trebled the cost of power in 10 years, and continue to threaten the currency, the liquidity of the South African government and the country's overall economic prospects. Any review of energy policy over this period has to begin by acknowledging that the strategic planning and implementation aspects of the sector, indeed for its overall management as a key sector in the economy, has been shocking. The extent to which this disaster can be laid at the door of the DST is questionable, since the

Department has only a limited mandate in the sector and can only serve its longer-term needs for technology and knowledge.

The other important critique of the energy strategy, as articulated in the TYIP targets, is that it perpetuated the unsustainable and environmentally damaging technologies which formed a crucial part of the previous socio-technical regime and its powerful military-industrial complex. It reinforced the dominance of coal as a source of energy, the myth of clean coal, the centrality of nuclear, and the minimisation of renewable energy. It paid lip service to the idea of environmental sustainability, to the extent that South Africa's Mpumalanga province has become one of the most heavily polluted places in the world. Any assessment of a government-led energy policy has to acknowledge these three important failures since 2008 – namely the diminishing affordability, the eroded security of supply, and the environmental disaster. The details of the DST programme seem somewhat insignificant in the context of these national crises.

Implementation of the energy grand challenge, broadly referred to here as the energy strategy, has formed a core part of the DST's activities since the adoption of the TYIP. Funding for the initiative, which was primarily a research activity, has on average accounted for about 20% of the total energy supply-related R&D, and amounted to a total of about R1.319 billion since the adoption of the TYIP.

The objectives of the energy strategy were outlined in the TYIP and also replicated in the Hydrogen strategy. Indeed, the latter has a more succinct and explicit set of objectives which have formed the basis for this evaluation. The objectives emphasised the requirements of the energy trilemma (energy security), energy equity (accessibility and affordability), environmental sustainability (reduced carbon emissions and other environmental footprints), with the important addition of energy efficiency, and referred to collectively as the 4Es. The latter were supplemented by the objectives of job creation through local manufacture and service SMMEs, and a platform for minerals beneficiation, particularly increasing the demand for platinum.

All of these objectives are supported by a strong rationale and are aligned with at least some of the other energy-related policies. However, the DST approach was not reflected in the Department of Energy's Integrated Resource Plan. This lack of alignment reflects the weakest aspect of the energy strategy, namely that it refers to a sector within which the DSI has limited control. In discussion with the officials from the DSI, a key learning point from the energy strategy is that the objectives of the TYIP reflected a confusion of mandates; the DST could not do the things that the plan required of it since they lay outside the DST mandate. It was also noted that the plan made the assumption that the same people could be used to do the R&D and to undertake the commercialisation. This assumption is misplaced; commercialisation requires an entirely different set of skills and cost structures. Moreover, the officials also commented that R&D-led innovation and industry development is limiting, with technology transfer perhaps being more important than R&D in the establishment of new sectors, and that innovation is not only product innovation – there is also process or approach innovation. Finally, it was noted that it is important to manage the expectations of grassroots entrepreneurs, who may have grandiose perspectives on the value of their inventions.

In terms of the overall perspective, it is noted that South Africa continues to score poorly on the Energy Trilemma Index, ranking 92 which is well behind Argentina, Brazil, Mauritius and other peer group countries. In this sense, the country's energy policy, which emphasises the importance of meeting all four components of the 4E's (the trilemma and energy efficiency), is poorly implemented and has not had the impact which is demanded of the sector and the country.

5.5 The Global Change Grand Challenge

5.5.1 Context and overview

The topics of climate change, global change or environmental sustainability are not addressed in the NRDS.

It is with the DST's TYIP that the Global Change Grand Challenge (GCGC) was formulated. The GCGC specifically focused on three main aspects, namely: "enhancing scientific understanding of global change, developing innovations and technologies to respond to global change, and understanding the social context within which solutions will have to be implemented" (DST, 2009: 2).[81] Global change is also framed within the context of scientific fields in which South Africa has a natural or geographical advantage. Due to South Africa's

[81] DST. 2009. *Global Change Grand Challenge National Research Plan*. [Extract from full document] Pretoria: Department of Science and Technology.

location, not only do researchers have the unique opportunity to investigate climate change, but their findings could benefit the country's biodiversity and increase international understanding for how earth systems operate. Furthermore, the sustainable solutions developed could be beneficial to the rest of the African continent. The outcomes for the GCGC, as articulated in the TYIP, are as follows (DST, 2008: 20):

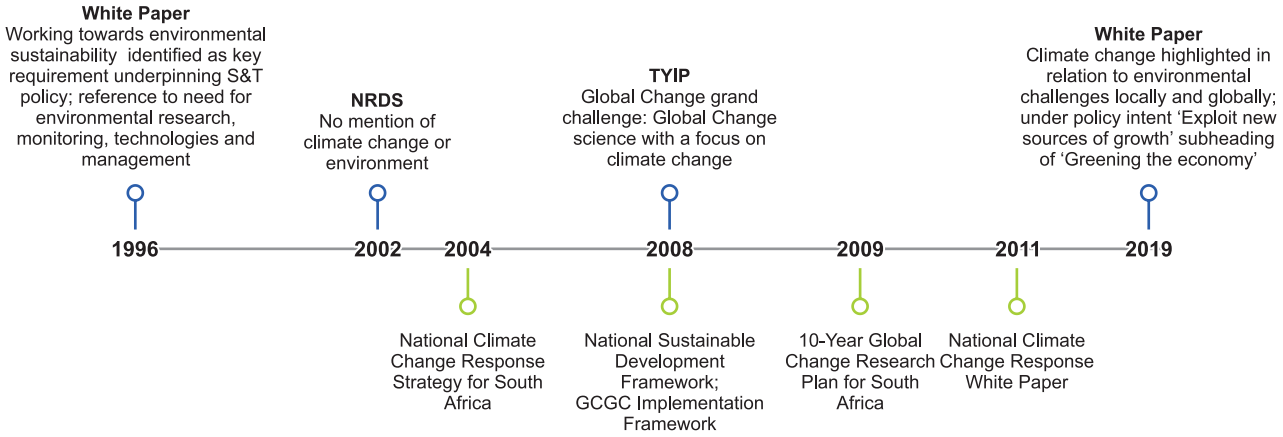
By 2018 South Africa anticipates that it will have:

- An internationally recognized science centre of excellence with climate change research and modelling capability, benefiting the entire continent
- Robust regional scenarios for the rate and impact of climate change and extreme weather conditions for South Africa and the continent
- Initiated climate change adaptation and mitigation actions
- An internationally recognized centre of excellence focused on the Southern Ocean and its contribution to global change processes
- Strengthened research and global monitoring capabilities on Marion Island, Antarctica and the Southern Ocean in partnership with other nations

The GCGC fits within the wider context of the United Nations Millennium Development Goals 2000-2015; the South African government's response to climate change; the socio-economic challenges faced by the country; and the research opportunities provided by South Africa's geographical location. Thus, the GCGC is developed in an international as well as national context, with the challenges for S&T situated in the broader challenge of sustainability.

A wide range of developments in both the national and international contexts have occurred over the past two decades that contributed to the GCGC. The very nature of global challenges calls for the coordination of various actors. Thus, developments include a wide variety of White Papers, Acts, frameworks, research plans, reviews, and the establishment of various new agencies in the country. Some of the key developments are shown in the figure below.

Timeline of key developments relating to the Global Change Grand Challenge



The DST's 2010 *10-Year Global Change Research Plan for South Africa* (GCRP) identified four cross-cutting research challenges and 18 research themes as per the figure below.

Knowledge challenges and research themes for the Global Change Research Plan

Understanding a changing planet	Reducing the human footprint	Adapting the way we live	Innovation for sustainability
• Observation and monitoring • Dynamics of the oceans around Southern Africa • Dynamics of the complex internal earth system • Linking the land, air and sea • Improving model predictions at different scales	• Waste-minimisation methods and technologies • Conserving biodiversity and ecosystem services • Institutional integration to manage ecosystems and ecosystem services • Doing more with less	• Preparing for rapid change and extreme events • Planning for sustainable urban development in a South African context • Water security for South Africa • Food and fibre security for South Africa	• Dynamics of transition at different scales – mechanisms of innovation and learning • Resilience and capability • Options for greening the developmental state • Technological innovation for sustainable social-ecological systems • Social Learning for sustainability, adaptation, innovation and resilience

5.5.2 Assessment

In the absence of access to the GCGC implementation plan, it was not possible to undertake a clarificatory evaluation of this grand challenge.

Our assessment of the implementation of the GCGC is based on the ASSAf 2016 *Mid-Term Review of the DST Global Change Grand Challenge*, which assesses implementation of the 10 key action points of the GCGC. The ASSAf review utilises the following rating scheme:

Achieved
Ongoing
Not achieved

Assessment of implementation of the 10 key action points of the GCGC

	10 key action points	Assessment
1	The development of an ambitious and comprehensive 10-year Global Change Science Plan for the broader National System of Innovation	
2	A complementary 10-year foresight and roadmap for innovation in adaptation technologies (with a focus on adaptation technologies related to climate change and its associated impacts)	
3	Introduction of enabling governance and management arrangements that would support co-ordination with the National System of Innovation to implement the Grand Challenge	
4	A specific HCD plan for the Global Change area which is informed by the overall Science, Engineering, and Technology Human Capital Development Strategy	
5	An integrated and consolidated programme for reducing the 'knowledge chasm' between research and action and to build the science-policy interface	
6	The need to build large-scale integrative flagship global change research programmes that can mobilise the research community	
7	The need for South Africa to identify opportunities for co-operation and alignment with continental and global efforts	
8	The introduction of a monitoring framework to support planning and reflection on the contribution of the Global Change grand challenge to science and technology, economic development, and environmental sustainability goals	

9	Support enhanced information dissemination, exchange and collaboration within the research community as well as between the research community, policy and decision-makers, and society	
10	The need for investments in research infrastructure and earth observations for the success of the Global Change Grand Challenge	

The assessment and discussion of the GCGC in the ASSAf mid-term review is divided into five sections: general points; scientific understanding; innovative technology development and response; decision-making and sustainability; and recommendations. Extracts from these discussions are provided below.

Overall, the panel concluded that the GCGC "is an important intervention" and should thus be continued as a grand challenge (ASSAf, 2016: 35). It highlighted notable contributions made through the GCGC, namely to scientific understanding in a number of areas, both nationally and internationally (ibid: 33); and to creating "a platform for building the next generation" through HCD in certain programmes (such as ACCESS and SAEON), and the establishment of permanent programmes outside of the GCGC funding framework in some universities (ibid: 35-36).

With regard to scientific understanding, the panel did note an imbalance with greater emphasis placed on the biophysical sciences, and less on socio-ecological and economic issues (ibid.: 33). In addition, measuring 'scientific impact' was difficult owing to a lack of "clear parameters or metrics" (ibid.). Similarly, the panel noted innovative technologies had been very limited and that most had emanated from the DST's Socio-Economic Innovation Partnerships Programme (ibid: 37). Furthermore, socio-economic research had been marginalised because of the "separation of the science and technology programmes at the DST" (ibid.). The review recommended that networks to facilitate interdisciplinary studies and research should be identified and/or created (ibid: 39).

The panel highlighted issues to do with funding, including the under-funding of some programmes, and limited funding for the research costs of students (ibid: 33). They suggested that it would be worthwhile exploring "how multiple sources of funding flow into the various programmes" and "developing a collective funding strategy" (ibid.). They recommended that adequate funding "be provided in a secre and continuous manner" for both student bursaries and research costs, and that a comprehensive funding database be established to allow for evaluation of the funds allocated (ibid: 39).

The review found limited evidence of the use of research findings by decision-makers, noting that the "DEA and the GCSC were tasked with the responsibility of knowledge transfer to decision-makers but this happened in an ad hoc manner as no formal processes were put in place" (ibid: 37). In this regard, the review recommended that "the channels of science-to-policy including all relevant government channels" should be formalised, and that a "mechanism of knowledge transfer to other stakeholders, including the business sector" needs to be developed (ibid: 39). In addition, "the GCSC should be capacitated to serve an overall coordinating scientific function; to synthesis [sic] scientific findings for dissemination to policymakers and the broader public and to identify gaps" (ibid.).

Finally, the review made a number of observations and recommendations relating to the overall management and coordinating function of the GCGC. Firstly, it noted that while the GCGC is intended to be a framework for "coordinating a number of separate and independent research groups" that, in practice, it did not constitute "a coordinated research initiative" (ibid: 33). Secondly, it recommended that a "dedicated overarching leadership and management structure needs to be established", together with "[e]xplicit roles, responsibilities and processes that need to be followed" (ibid: 39). Thirdly, the review made recommendations regarding monitoring and evaluation, including that related to "analyses into the research being undertaken and reporting on whether the science of the GCGC is being achieved", as well as the need for an overall monitoring and evaluation framework and associated performance scorecard for the remainder of the implementation of the GCGC (ibid.).

5.6 The Human and Social Dynamics Grand Challenge

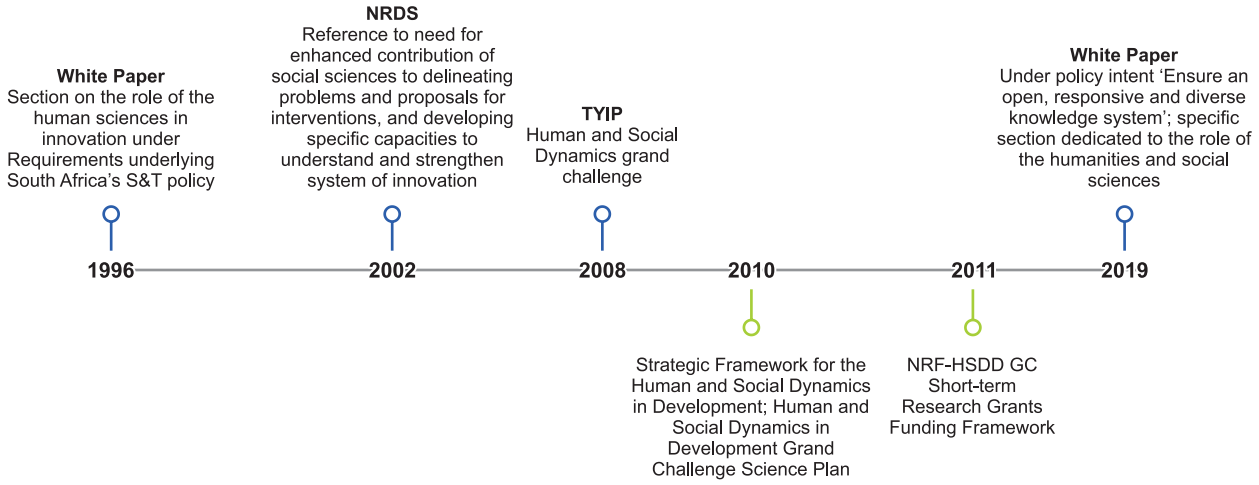
5.6.1 Context, overview and strategic objectives

The goals of the TYIP's Human and Social Dynamics Grand Challenge (HSD GC) were: "to increase our ability to anticipate the complex consequences of change; to better understand the dynamics of human and social behaviour at all levels; to better understand the cognitive and social structures that create and define change; and to help people and organisations better manage profound or rapid change" (DST, 2008: 20).

Following the TYIP, the DST released its *Strategic Framework: Human and Social Dynamics in Development* in January 2010 "to give impetus to research in human and social dynamics to create a better life for all" (DST, 2010: 3). In July of 2010, the DST released its *Human and Social Dynamics in Development Grand Challenge* (HSDD GC) Science Plan. The core of the document is about providing a framework and guide to government's approach to research support in the grand challenge. The focus is on the development, production and dissemination of research, as well as the instruments and modalities through which support will be provided, thereby implementing the Science Plan. This was followed in 2011 by the NRF's *HSDD GC Short-term Research Grants Funding Framework*.

An overview of key national-level developments relating to the human and social sciences is provided in the figure below.

Key national-level developments relating to the human and social sciences



The terminology used to describe the HSD GC in the TYIP is not uniform. The HSD GC and the other four grand challenges are referred to as "strategic outcomes" (p4), "core projections for 2018" (p1) and "areas of the highest socioeconomic return" (p5). Although HSD is presented as a separate grand challenge, the TYIP has an understanding that HSD is "at the core of nearly every major challenge facing South Africa – from climate change to creating a competitive and innovative workforce" (ibid.: 20). The table below is the reviewer's attempt to summarise the logic of the HSD GC as an intervention. It is important to note that, besides this summary, the TYIP does not offer much more in terms of capturing the essence of the HSD GC.

Logic of the HSD GC as an intervention, constructed from the TYIP text

Overarching main goal[82]	Sub-goals specific to the HSD GC	Anticipated/desired interventions	Outcomes
South Africa's transformation towards a knowledge-based economy	Four sub-goals: • To increase our ability to anticipate the complex consequences of change • To better understand the dynamics of human and social behaviour at all levels • To better understand the cognitive and social structures that create and define change • To help people and organisations better manage profound or rapid change	DST will develop a long-term programme to increase basic understanding of human behaviour. Computer modelling will be applied increasingly to cognitive, socio-cultural, developmental, and neurobiological studies to understand how people learn. In the area of decision-making and risk, the study of individuals' responses to risk, their judgment in selecting options among the choices available, the perception of uncertainties facing us in today's world, and the treatment of risk in collective and private decisions are all highly dependent on the work of cognitive, behavioural, and social psychologists. Address the need for improved, science-based information to direct development-oriented decision-making. Develop instruments to harvest technology from publicly-funded research activity and put it to use on a not-for-profit basis to improve the lives of the poor. Support the public understanding of and engagement with science.	Three outcomes by 2018: • Applied science and technology activities to achieve the Millennium Development Goals on livelihoods and affordable access to services • Recognition as a "knowledge hub" on social sciences research in Africa • Socio-culturally based models that accurately reflected the learning behaviour of the South African national system of innovation

[82] Resulting from the interplay between five grand challenges and four drivers/enablers.

Various mentions of the HSD GC of the TYIP in the Strategic Framework for the Human and Social Dynamics in Development, as well as a close reading of the Strategic Framework, allow for an alternative reconstruction of the HSD GC, as per the table below.

Logic of the HSD GC as an intervention, constructed from the Strategic Framework text

Objectives of the HSD GC	Anticipated/desired interventions	Outcomes of the HSD GC
To increase and deepen research to improve scientific understanding and practice in a range of fields, while contributing to the development of evidence-based public policy that improves the human condition	Develop a structured research agenda, with four areas of focus: • The dynamics of human and social behaviour • Science, technology and society • Social cohesion and identity • Societal change and the evolution of modern societies Allocate resources to grow the research base, including support for university libraries Develop a work programme for longitudinal studies in the humanities and social sciences Develop a plan for public engagement • Series of stakeholder dialogues • Series of role player seminars and workshops Develop community-university partnerships	Three outcomes by 2018: • Much-expanded base of research and knowledge, providing internationally accredited research into the humanities and social sciences in a fast-changing world • Evidence-based public policy initiatives that have helped to improve the human condition • Recognition of South Africa's unique positioning in opening up exciting possibilities of research in both the humanities and social sciences The Strategic Framework further specifies the "outputs" of the HSD GC as: • New knowledge: internationally accredited research • Public policy interventions • Evidence-based decision-making • Social returns (quality of life gains) • Greater fundamental theoretical understanding of structures and processes and the capacity to model them • Greater capacity to generate novel hypotheses with implications for new instruments and research methods • Cost-efficient and effective R&D

5.6.2 Assessments

Our assessment of the implementation design for this grand challenge is provided in the table below.

Well addressed
Moderately well addressed
Poorly addressed or not addressed at all

Assessment of implementation design

Is any reference made to problems or challenges being addressed by the strategy/plan?		Yes. The HSDD Strategic Framework (p3) states that humanities and social sciences (HSS) "dynamics are at the core of virtually every major challenge facing South Africa and the African continent – from improving education and skills to reducing crime; from curbing the spread of HIV/AIDS to developing a sustainable approach to energy; and from reducing xenophobia to building more inclusive communities; and extends to the creative arts. To respond to these developments, and to improve the way our society works, we need to better understand social behaviour in all its forms."
Are the goals and objectives clear and unambiguously formulated?		Yes; both the TYIP and the Strategic Framework contain statements that can be interpreted as either goals or outcomes. However, the goal statements are not equally clear.
Are the intervention activities, and those responsible for undertaking these activities, clearly specified?		The 'reconstructed' interventions (see tables above) refer to different activities that are not always sufficiently specific and concrete. In some cases, evidence of the introduction (or not) of a particular 'intervention' (yes/no) could be regarded as an indication of action taken. However, the interventions are broad and multifaceted and most probably require more refined measures. The Strategic Framework mentions universities and science councils (specifically the HSRC and CSIR), as well as the NRF, as key stakeholders in the implementation of activities. The SARChI and CoE initiatives are also central to implementation.
Is a budget for the interventions provided?		According to a senior DST official, the HSD GC was never properly budgeted for, both in terms of project/programme funding and human resources. This was a serious omission on the part of the Department because it meant that the GC could never be fully implemented.
Are targets and milestones included?		There are no projected targets or milestones other than describing an ideal situation by 2018.
Are intervention outputs clearly specified?		'Outputs' referred to are not actually outputs and are very broadly defined.
Are interventions outcomes clearly specified? Is a distinction made between short- and medium-term outcomes?		The outcomes extracted from the TYIP and Strategic Framework are not consistent across the two documents and no distinction is made between short-, medium-, and long-term outcomes.
Are any indicators (mostly of outcomes and impact) specified? Are these indicators clear and concrete and measurable?		Not in the HSDD Strategic Framework or in the HSDD GC Science Plan.

Assessment of the implementation of the interventions and associated activities for this grand challenge is provided below.

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation for the HSD Grand Challenge

Intervention category	Instrument used	Agency	Period		Comment	Evidence	Funding
Develop a long-term programme to increase basic understanding of human behaviour; a work programme for longitudinal studies in the humanities and social sciences.	?	DST			No information		
Apply computer modelling to cognitive, socio-cultural, developmental, and neurobiological studies to understand how people learn.	?	?			No information		
Develop a structured research agenda with four areas of focus.	HSS (Humanities and Social Sciences) Research Grants	NRF	2011-2020		Three rounds of research projects funded	NRF funding records	R67,806,000
Develop community-university partnerships.	Community-University Partnership Programme (CUPP) for historically disadvantaged institutions	NRF	2009-2012		NRF funding allocation	NRF funding records	R16,531,000
Support the public understanding of and engagement with science; stakeholder dialogues and role player seminars and workshops.	HSD Research Seminars	HSRC	2014-2017		351 seminars convened by 30/03/2019; 3 public dialogues convened by 30/03/2019; 9 policy dialogues convened by 30/03/2019	DST records	R14,838,000
	Innovation for Inclusive Development (IID) Seminars	HSRC	2015-2019				R10,189,034
Address the need for improved, science-based information to direct development-oriented decision-making.	Government Cluster Policy Workshops	HSRC	2011-2014		21 workshops convened by 30/03/2019; 176 policy-relevant knowledge products by 27/03/2019	DST records	R10,197,000
Allocate resources to grow the research base.	HSS SARChI Chairs	NRF	2009-2020		570 HSDD academic publications by 18/07/2019; 39 HSS SARChI Chairs funded	NRF funding records	R271,918,000 (figure incomplete; only 2009-2015)
	HSD Research Internship Programme	NRF	2011-2014				R20,175,000

Intervention category	Instrument used	Agency	Period		Comment	Evidence	Funding
	Human and Social Sciences Analysis	HSRC	2011-2020			DST records	R167,518,000
	Development of Research Capacity for the Human and Social Sciences Research	HSRC	2017-2020				R72,138,000
Allocate resources to grow the research base – specifically support for university libraries.	?	?			No information		
Develop instruments to harvest technology from publicly funded research activity and put it to use on a not-for-profit basis to improve the lives of the poor.	Spatial and Temporal Evidence for Planning in South Africa (stepSA)	CSIR & HSRC	2008-2010 & 2011-2015		Received DST funding support	DST records	R37,900,000
	Rural Innovation Assessment Toolkit (RIAT)	HSRC TIA	2012-2018 2018-2019				R19,722,906
	Monitoring, Evaluation, Reflection and Learning (MERL) Framework for the Cofimvaba Rural Education Initiative	HSRC	2013-2016				R5,552,922
	Spatial Monitoring of Informal Settlements and Land Invasion in Sustainable Human Settlements – Decision Support Tool	TIA	2015-2018				R7,491,809
	Urban Knowledge Hub – Decision Support Tool	CSIR	2015-2020				R3,939,726
	ICT Maturity Tool for Schools	TIA	2017-2018				R2,000,000
	KZN Technology for Rural Education and Development (Tech4RED)	TIA	2017-2018				R3,225,000
	Sustainable Human Settlements Decision Support Tool	TIA	2017-2018				R3,000,000

Our review of the HSD GC shows that more recent events have somewhat caught up with the original intent of the GC. The policy intents of the 2019 White Paper underscore the importance of the HSD's full body of work as holistic and intersectional, and reflects critical perspectives as well as alignment with the NDP and the NSI.

As to the implementation of the HSD GC, our review showed that two major challenges were experienced: inadequate funding and human resource constraints. The funding constraint has been mitigated somewhat through EU funding and 'creative appropriation' of unspent budgets within the DSI and the entities. It is clear that this grand challenge was never properly budgeted for.

It is also evident that the strategy should have been implemented differently and that the human and social sciences should have been mainstreamed from the outset throughout all of the DST's programmes (and indeed all the grand challenges) and mega-science and flagship projects.

Despite the problems with the implementation of the strategy and the decision that it will be addressed differently once the new decadal plan has been developed, there is evidence of some gains and achievements to date. In the words of a DST official: "The HSDD has reminded stakeholders and role-players to consider the cultural and institutional contexts, and the modes of discourse, that accompany and embed processes of techno-scientific innovation; it has provided a platform for addressing the nature and possibilities for the HSS and the role the HSS can play in addressing social issues, government priorities (nine point plan, NDP and the triple challenge), and deepening understanding of the human condition; and it has demonstrated that STI is inextricably bound to human interests and social practices. There is a strong sense in society that STI is overly abstract and theoretical. STI is simply seen as the application of scientific reasoning, rather than viewed as a social phenomenon. If a technology is made and used by human beings then it cannot help but reflect human ends, values and ideas. Society simultaneously shapes technology as technology shapes society."

In the final analysis: "the HSDD GC created an approach to research and innovation that fosters productive research in the human and social dimensions of STI. The HSDD GC broadened the notion of innovation to the HSS by acknowledging a wider range of knowledge available in different sectors of society. This underscored a need for more serious scrutiny of prevailing understandings of 'science' and 'society'. This GC put the spotlight on the HSS as producers of socially and policy-relevant knowledge. The NSI began to seriously engage with the HSS as important actors in the processes of producing innovations. It also:

- Fostered reflexivity about the science–society interface;
- Provided a unique antenna function for society's current and future demands for HSS;
- Addressed societal challenges requires understanding human aspirations, institutional constraints, social conflicts, value choices and power dynamics;
- Provided a platform to broaden and enrich the conversation on what we mean by 'innovation', 'science' and 'technology', and 'technology transfer and technology demonstration' in primarily rural areas; and
- Provided best practice guidelines to enable and support rural-based enterprises to improve productivity through innovative technology solutions."

The concluding assessment by the DSI official is that "the HSDD GC has contributed to moving the needle in the NSI's understanding of STI beyond the gloomy legacy of technological determinism, neutrality and autonomy. By rethinking and renewing the starting point for an understanding of the relationship between STI and society. HSDD GC has created a space for the NSI to think rationally about the ways in which STI reflect as well as change life on an individual, social, cultural and ecological level. The HSDD GC created an approach to research and innovation that fosters productive research in the human and social dimensions of STI. The HSDD GC broadened the notion of innovation to the HSS by acknowledging a wider range of knowledge available in different sectors of society. This underscored a need for more serious scrutiny of prevailing understandings of 'science' and 'society'. This GC put the spotlight on the HSS as producers of socially and policy-relevant knowledge. The NSI began to seriously engage with the HSS as important actors in the processes of producing innovations."

CHAPTER 6

FINANCING

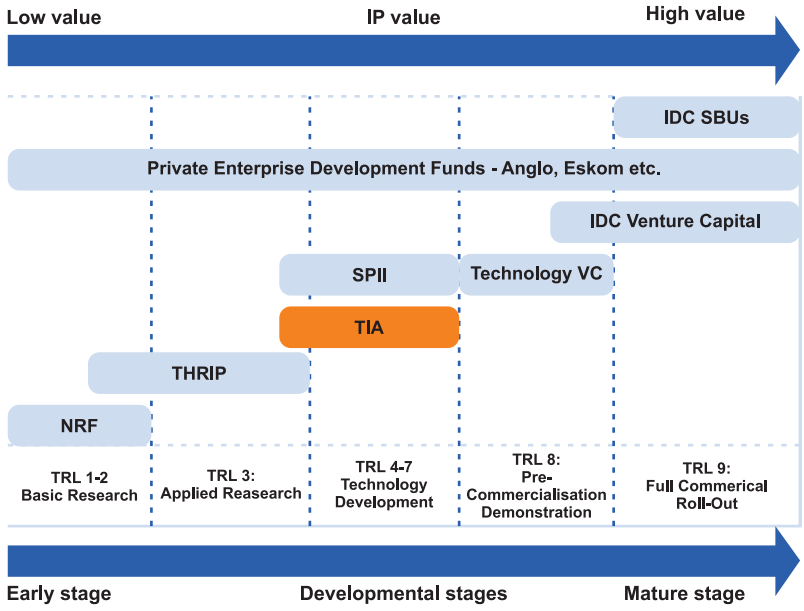
6.1 Introduction

This chapter is devoted to a summary of three reviews that were conducted by the team related to the financing of STI. These are:

- The Technology Innovation Agency
- The Innovation Fund, and
- The R&D Tax Incentive.

Although there are obviously numerous innovation funding instruments (see figure below), our Terms of Reference only required us to review those organisations (FTI/TIA) or funding instruments explicitly referenced in the NRDS or TYIP.

The innovation funding landscape[83]



6.2 The Technology Innovation Agency

6.2.1 Introduction and overview

In 2002, the NRDS proposed the establishment of a Foundation for Technological Innovation (FTI) that would provide a "key structural intervention … to support the government in stimulating and intensifying technological innovation" (DST, 2002: 38). The key attributes of the FTI would be to: "establish capacity to identify, coordinate and finance

[83] Source: TIA. 2014. *Strategic Plan* FY2015-FY2019. Pretoria: Technology Innovation Agency.

the new technology and innovation missions"; draw together and integrate the management of disparate innovation, incubation and diffusion initiatives" (e.g. the Innovation Fund, the Support Programme for Industrial Innovation and the Technology Stations Programme, Tshumisano); "create and synergise innovation activities linked to universities and research organisations"; manage IP, especially that derived from publicly financed research; strengthen initiatives for the commercialisation of IP; and establish "programmes for small and BEE businesses to source technology internationally when not available locally" (ibid: 39-40). The NRDS noted that these functions would be initiated within the DST and that "further research and investigation [would] be undertaken to determine the most optimal ultimate institutional form" (ibid: 39). The establishment of what eventually became the TIA was thus a central goal of the NRDS, being advocated to address the 'innovation chasm' and other system defects that the strategy had noted.

The establishment and operationalisation of the FTI–TIA took eight years. During the period 2005-2007, progress toward establishing the FTI accelerated. Based on two reports – the in-house 'lost opportunity survey' (Modiba, 2006)[84] and the DST-commissioned independent business case (Pedlar & Kahn, 2007)[85] – as well as recommendations of the Finland-funded COFISA consultancy, the DST proposed an institutional model for the FTI based on the Finnish Funding Agency for Technology and Innovation.

In 2008, the TYIP announced the establishment of the TIA, which would "address the fragmentation of funding instruments" (DST, 2008: 22). The Technology Innovation Agency Act No. 26 of 2008 was approved in August 2008 and commenced on 4 April 2009. The Act stated that TIA's object was to "support the State in stimulating and intensifying technological innovation in order to improve economic growth and the quality of life of all South Africans by developing and exploiting technological innovations." This framework allowed for the merging of the Innovation Fund, the four Biotechnology Regional Innovation Centres, Tshumisano, and the Advanced Manufacturing Technology Strategy Implementation Unit.

The TIA became a trading entity as of 1 April 2010. The organisation experienced a range of problems during its first five years (see the full review: Annexure 3 in Volume 5). In 2013, the Minister of S&T appointed a panel to undertake an external institutional review of the TIA. In 2015, a new CEO was appointed who, along with a new Board, and equipped with the recommendations of the ministerial review, developed a new strategic plan for 2015-2019 and set out a new position for the Agency within the innovation funding landscape. The strategic objectives of the TIA outlined below are based on this new positioning.

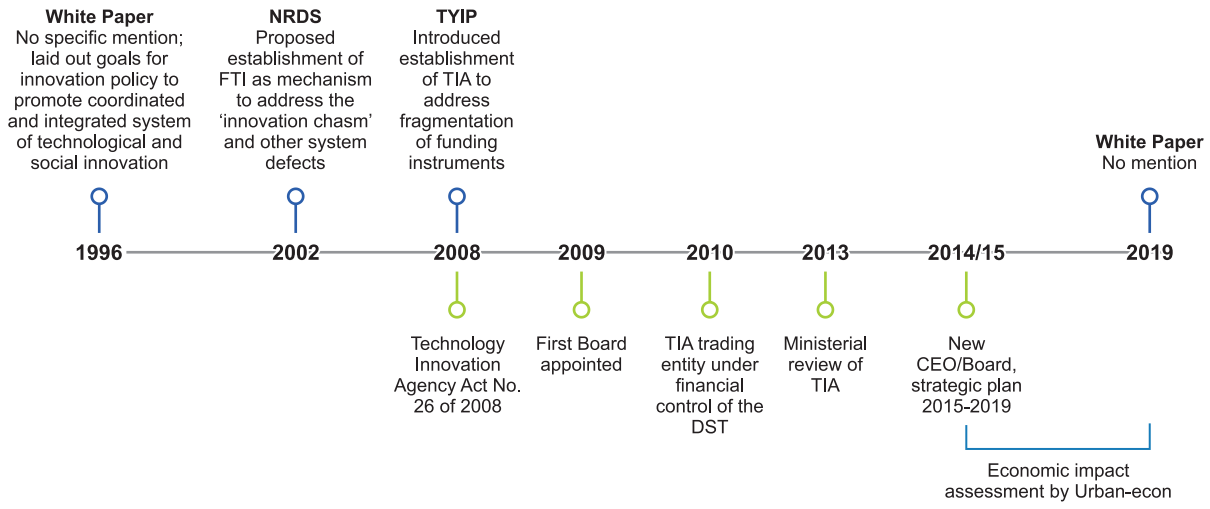
TIA strategic outcome oriented goals and strategic objectives (2015-2019)

Mandate	To support the state in stimulating and intensifying technological innovation in order to improve economic growth and the quality of life for all South Africans by developing and exploiting technological innovations	
Strategic outcome oriented goals	1	To support the commercialisation of technological innovations
	2	To increase infrastructure access for technology development
	3	To stimulate an agile and responsive NSI
Strategic objectives	1	To provide technology development funding and support in high impact areas[86]
	2	To provide thought leadership and an enabling environment for technology innovation in collaboration with role players[87]
	3	To develop an effective and efficient internal environment to successfully execute the strategy

[84] Modiba T. 2006. Lost Opportunity Survey Report. Foundation for Technological Innovation. Pretoria: Department of Science and Technology.
[85] Pedlar P & Kahn MJ. 2007. Establishment of the Technology Innovation Agency. Business Case V 3. Pretoria: Department of Science and Technology (unpublished).
[86] Originally formulated as: "To provide customer-centric technology development funding and support".
[87] Originally formulated as: "To stimulate an enabling environment for technology innovation in collaboration with role-players".

Key developments relating to the TIA are captured in the figure below.

Timeline of key developments relating to the TIA



6.2.2 Assessment

The assessment of implementation/performance of the strategic objectives and strategic outcome-oriented goals against KPIs and targets in the tables below draw on the information provided in the TIA Annual Report 2017/18 (most recent available).

Achieved
Partially achieved
Not achieved at all
Not possible to make a judgement

Assessment of implementation of strategic objectives (2017/18)

Strategic objectives	KPIs		Evidence	Comments
Provide technology development funding and support in high impact areas	No. of technologies, processes or services advancing by two or more TRL levels		Target: 26 Achieved: 34	*The overachievement is due to a contribution from the Seed Fund Programme that saw projects funded in previous years reaching maturity during FY2017/18.*
	No. of innovation project outputs taken up in the market		Target: 10 Achieved: 19	*The overachievement is due to contributions from the Seed Fund Programme, Technology Innovation Cluster Programme and the Technology Platform Programme (TPP).*
	Amount of additional funding attracted into TIA's portfolio		Target: R113m Achieved: R117m	*TPP attracted R54m of the total additional income to fund operations and research activities.* *Additional funding generated through partnership projects.*
	Amount of income received/ recognised		Target: R142m Achieved: R67m	*The entity committed to a much stretched target compared to FY2016/17. The hub-and-spoke model will be integrated in FY2018/19. An optimistic target coupled with economic pressures resulted in lower than expected income.* *The entity had limited cash reserves, as opposed to the previous financial periods for funding. New programmes were secured from DST such as the Innovation for Inclusive Development Programme, the Forestry Genomics Programme and the Agriculture Bio-economy Programme. The full integration of these programmes will occur in the FY2018/19.* *The entity amended its income recognition criteria to align with that of the Generally Recognised Accounting Practices and this amendment was implemented in Q3 of the year under review. The entity received a total of R116 087 000 cash during this financial year, most which will be disbursed in FY2018/19.*

Strategic objectives	KPIs		Evidence	Comments
Provide thought leadership and an enabling environment for technology innovation in collaboration with role players	No. of knowledge innovation products produced as a result of TIA funding and support programmes (prototypes developed, IP, technology demonstrators developed, technology transfer packages)		Target: 83 Achieved: 98	*It is not clear what the term 'knowledge innovation products' mean or refer to. It is more than likely that this is a conflation of the DST's combined 'knowledge and innovation products'. If that is the case, one needs to take the stated evidence with a pinch of salt.*
	No. of knowledge innovation projects produced by TIA-supported programmes receiving third party funding		Target: 27 Achieved: 31	*Through the innovation enabling environment and the networks built within the NSI, the entity is proud to report that projects supported through the TICP, TPP and TSP could secure additional funding.*
	No. of SMMEs receiving technology support		Target: 2,800 Achieved: 2,800	*It seems rather suspicious that the number of SMMEs receiving support is identical to the target.*
	No. of PDI owned SMMEs assisted as percentage of total projects supported, receiving funding, support and/or technology services from TIA		Target: 65% Achieved: 54%	
	No. of technology innovation initiatives (conference papers, presentations and posters, policy recommendations, panel discussions, position papers, publications, think tanks; relating mainly to keynote addresses) undertaken by TIA.		Target: 31 Achieved: 73	*[TIA] has spent a significant amount of time to enhance thought leadership within the NSI, working in collaboration with other role players both locally and internationally. Further emphasis was given to the Africa Initiative and interaction with HEIs and science councils.*
Develop an effective and efficient internal environment to successfully execute the strategy	Investment approval turnaround time		Target: 16 weeks Achieved: 27 weeks (YTIP)	*This objective was not met. TIA has embarked on a work-study to streamline its processes and reduce our turnaround time by simplifying its processes and supporting stakeholders better. A predictive call process will be implemented in 2018/19.*
	Improve adequacy and effectiveness of the control environment		Target: ISO 9001 Certification Achieved: ISO 9001 Certification	*One could ask whether it is appropriate for an organisation such as TIA to aspire to have ISO certification. ISO certification is most applicable in industries such as manufacturing – not for innovation agencies.*

Strategic objectives	KPIs		Evidence	Comments
	Amount of funds utilised for projects and programmes as a percentage of the total actual expenditure		Target: 70% Achieved: 66%	*With limited cash resources for FY2017/18, TIA was under pressure to raise additional income to attain the targeted ratio. Unfortunately, this was not possible as less income was recognised than anticipated. TIA, however, managed to contain its administrative expenditure and remain within budget.*
	Functional organisational structure as measured by vacancy rate		Target: <11% Achieved: 8.1%	*The attrition rate stabilised over the past two years, rendering it no longer a high operational risk.*
	Effective implementation of talent management strategy – employee engagement ratio		Target: 3.8 Achieved: 3.8	

Assessment of implementation of strategic outcome oriented goals (2017/18)

Strategic goals	KPIs	Target 2015/20	Cumulative planned performance 2015/16-2017/18	Cumulative actual performance 2015/16-2017/18		Comments[89]
Support commercialisation of technological innovations	Amount of income recognised	R655,3m	R363,1m	R331,6m		The reduction in funding raised is attributed to poor economic conditions that have led to a reduction in the funding available. Activities herein for the remaining period have been streamlined and targeted interventions have been planned to ensure that the funds are raised to support innovations.
	No. of innovation project outputs taken up in the market	51	28	49		
	No. of technologies, processes or services advancing by wo or more TRL levels	102	44	92		Of TIA's total portfolio funded in FY2017/18, 34 projects advanced by two or more [TRLs] with some reaching the demonstration stage. This is an increase of three from the 31 projects realised in FY2016/17 and 27 over FY2015/16. The Seed Fund Programme was again the key contributor to the results attained. The moderate increase is attributable to the level of maturity of the portfolio.

[89] Direct quotes from 2017/18 annual reports italicised.

Strategic goals	KPIs	Target 2015/20	Cumulative planned performance 2015/16-2017/18	Cumulative actual performance 2015/16-2017/18		Comments
Increase infrastructure access for technology development	No. of knowledge innovation products produced as a result of TIA funding and support programmes	350	159	238		
	No. of SMMEs receiving technology support	14,200	7,000	7,258		The Technology Station Programme (TSP) has continued to deliver effective technology support services to SMMEs, particularly with regards to product and process improvements, prototype development and technology absorption services. … The continued performance of these programmes highlights the continued demand for such services.
Stimulate an agile and responsive NSI	Amount of additional funding attracted into TIA's portfolio	R551m	R247m	R397,3m		
	No. of technology innovation initiatives undertaken by TIA	124	44	152		

TIA had a very difficult birth. With the benefit of hindsight this was to be expected. Globally, mergers and acquisitions have very high failure rates. Forced mergers can hardly be expected to be different. In the TIA case, six trusts were merged. The fact that the trust structure did not comply with the PFMA was known at least three years before TIA became operational. It is now well-known that there was a governance and oversight failure from the start. Whether one can lay the blame at the DST's feet is another thing. What is clear is that the resultant 'havoc' should have been managed better. There seems little evidence of an organisational learning.

The TIA drew inspiration from the perceived success of TEKES in Finland, a country with a GDP one third of South Africa's, but a population the tenth of its size; in other words, a wealthy country, with perhaps the strongest education system in the world. Finland is also strong in the export of high-technology goods; South Africa is not. In that environment, technologically already advanced relative to South Africa, TEKES revenue was 20-fold greater in nominal Rand terms. TEKES can be very generous; TEKES can take risks. This raises the fundamental question – why a TEKES-like model? What persuaded policy leadership to attempt to emulate Finland? Could a TEKES lookalike flourish in the completely different South African monetary policy environment? The evidence to date would suggest not.

The above remarks speak to the 'negatives' and 'positives'. What remains is to offer recommendations regarding the future of the TIA. It is one matter to assess an organisation against its own objectives; it is another matter to ask whether the objectives measure what should be measured, and indeed whether the Agency is fit for purpose.

TIA exhibits behaviour quite different to those envisaged in the NRDS and the early TIA Business Case. In our view, this calls for a comprehensive and external review of the mission and strategic objectives of TIA. Such a review must revisit the premises for the creation of the TIA. Whatever the outcome of that exercise might be, the mechanisms for selection of funding proposals, the desirability, if at all, of demanding an equity stake, or IP stake, and the mechanisms for project exit, require careful re-consideration. Such a review must appreciate both the complexity and diversity inherent in the Agency. Our final recommendation then is for a review that follows an open and exploratory process without any pre-determined set of outcomes in mind.

6.3 The Innovation Fund

6.3.1 Introduction and overview

The 1996 White Paper on S&T set out goals and objectives for the Innovation Fund, which was intended to provide direct incentives across the innovation system. This extended the reach of the then Science Vote to the private sector. As such, the Fund would "promote large-scale projects, involving participants from throughout the national system of innovation" which would "focus attention on the major themes of government pertinent to this White Paper, namely competitiveness, quality of life, environmental sustainability, and on harnessing information technology to the needs of our society and economy" (DACST, 1996: 29). Its objectives would be:

- To permit a reallocation of resources from the historical patterns of government science towards the key issues of competitiveness, quality of life, environmental sustainability and harnessing information technology;
- To increase the extent to which funds for the activities of government SETIs are obtained via competitive processes; and
- To promote increased networking and cross-sectoral collaboration within South Africa's national system of innovation.

The Innovation Fund would initially obtain its income from a reprioritisation of the science allocations across government.

The Innovation Fund was established within DACST in 1997. By late 1999, the increasing management burden of operating the Innovation Fund led DACST to look for an alternative home for the Fund, and in due course the asset was transferred to the NRF. The NRF performed the management function as provided for in the Innovation Fund Trust Deed (DACST, 2000) that allowed for the appointment of a Board of Trustees empowered to enter into a management contract with a competent organisation/individual that was expected to establish a properly staffed Innovation Fund Office. The Director-General of DACST was designated as the Chair of the Board.

The objectives of the Innovation Fund outlined in the White Paper were incorporated into the 2000 Innovation Fund Deed of Trust.[90] Taking these two documents together, the strategic objectives of the Innovation Fund are summarised below.

Innovation Fund strategic objectives

Mission	Through competitive funding to involve participants from throughout the national system of innovation that will focus their projects on the major themes of government	
Strategic objectives	1	Promote large-scale, longer-term projects leading to technological innovation within the research community
	2	Promote the key issues of competitiveness, quality of life, environmental sustainability and harnessing of information technology
	3	Promote multidisciplinary and cross-sectoral collaborative research and development programmes within the national system of innovation
	4	Own the assets and run the affairs of the Innovation Fund
	5	Ensure regular updating of funding priorities

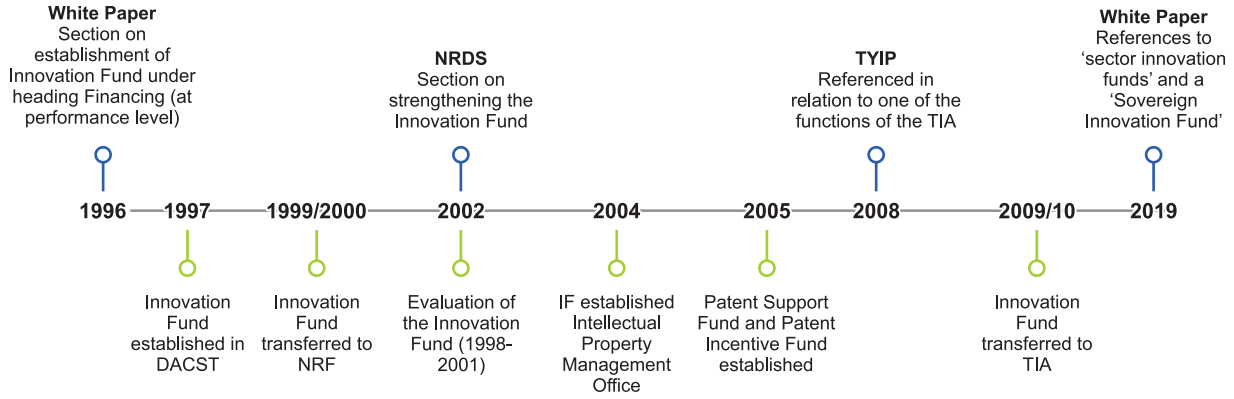
The main Innovation Fund vehicle was the Technology Advancement Programme. In the early years of the Innovation Fund, key thematic areas were promoted with annual calls for proposals. By 2008, the Fund accepted proposals on a continuous basis in all fields. Finance was in principle available for all stages of the development cycle including what were termed 'venture capital loans' (the 'Seed Fund') and assistance toward the cost of patenting.

Whilst in the NRF, the Innovation Fund grew task-specific management skills, especially in the area of IP management, and established the Intellectual Property Management Office (IPMO) in 2004. The Innovation Fund also instituted the Patent Support Fund for Research Institutions to subsidise patenting costs of publicly-financed research institutions, and supported the patenting costs of SMMEs, especially those deemed to meet black economic empowerment criteria. A Patent Incentive Fund was also created to incentivise researchers of publicly-financed research institutions to file patent applications.

The Innovation Fund remained in the NRF until the 2009/10 financial year when its transfer to the TIA was finalised. Over its roughly 10-year life, the Innovation Fund received in the order of R1.2 billion of public funds for the support of research ventures.

Key developments relating to the Innovation Fund are captured in the figure below.

Timeline of key developments relating to the Innovation Fund



[90] DACST. 2000. *Innovation Fund Trust: Deed of Trust.* (unpublished) Pretoria, Department of Arts, Culture, Science and Technology.

6.3.2 Assessment

Assessment of the implementation of the Innovation Fund against its strategic objectives is provided below.

Assessment of implementation of the strategic objectives of the Innovation Fund

Intervention		Comments	Evidence
Promote large-scale, longer-term projects leading to technological innovation within the research community		Qualified success	Innovation Fund annual reports 2006-2009
Promote the key issues of competitiveness, quality of life, environmental sustainability and harnessing of information technology		Qualified success; although very difficult to quantify	
Promote multidisciplinary and cross-sectoral collaborative R&D programmes within the national system of innovation		Qualified success	
Own the assets and run the affairs of the Innovation Fund		Qualified success	
Ensure regular updating of funding priorities		Qualified success	

Evaluating the implementation of the Fund presents many difficulties, with little available documentary evidence that explains or quantifies its journey. Furthermore, the goals of the Fund shifted over time, starting from its declared alignment with the goals of government, through to a period of directed funding, and finally allowing researcher-led bottom-up solicitations for support. In addition, fund management resources were channelled into two new sub-structures, the Innovation Fund Commercialisation Office and the Intellectual Property Management Office, as well as education and training activities, competitions, and advocacy efforts. Each of these activities would require their own assessment.

What may be of value is a brief examination of a selection of the 232 projects funded by the Innovation Fund as highlighted in the Innovation Fund Annual Report 2007/08. These are highlighted in below, with a brief assessment of their evolution to the present.

A selective appraisal of Innovation Fund projects

Project	Comment
Joanna Solar	Despite many years of research, and international patents, appears to have been squeezed out of the market by Chinese competition. Innovation Fund and later IDC gave support.
Adept airmotive	Niche aero-engine developer. Ongoing.
Geratech	Zirconium refining and product development based on 1980s know-how. Innovation Fund funded. Closed down.
Eyeborn	Ceramic eyeball development with early Fund support. Ongoing.
Red Five Labs	Innovation Fund, Shuttleworth HBD VC and then Fedgroup supported app platform. Terminated in 2010 as Nokia lost market dominance.
Electric Genetics	Genomic platform. Abandoned.
Justick	Patented. Successful small-scale enterprise.
Sunspace	Terminated and absorbed into Denel.
Blue Cube Systems	Successful mineral processing software application. 13 international patents, including US.
Vibol	Loan to an existing company.
Safe eggs	Innovation Fund funding to Eggbert Co (Pty) Ltd for microwave pasteurisation. Successful.
Optimal Energy	Electric vehicle project received R300 million of Innovation Fund and IDC funds. Abandoned in 2012 due to lack of investor interest to move to production scale.

Given the absence of regular output, outcome or impact evaluations, it is risky to attempt such in this review. One insight is that of the 232 projects that the Fund supported, one might reasonably expect notable success in perhaps 10 instances. Joanna Solar is an example of a research project moving into commercial technology that appears to have followed the textbook model. Yet it has not achieved the market share that one might have hoped for. It is not one of the 'big 10'.

As to employment 'creation', the Innovation Fund annual report for 2008/09 reported that 304 jobs were supported. Of these, 91 were in Optimal Energy that ceased trading, 110 were associated with the already functioning Geratech, making it difficult to arrive at a precise statement of job creation. The same report states that the lifetime investment of R1.2 billion had generated returns in the order of R2 million.

Yet there are Innovation Fund success stories that have not been told. One is the University of Pretoria/CSIR/HSRC application of operations research methods to the location of mobile phones by triangulation of cell phone tower pings. This project, which matured in 1999, provided robust forensic evidence that was pivotal in the conviction of members of three hijacking syndicates. The social return on investment was high, yet the project never received due public recognition.

In conclusion, it might be correct to aver that the main achievements of the Innovation Fund are that it contributed to building collaborative networks, attained some notable successes, encouraged many researchers in their work, and contributed to making researchers more aware of the importance of recognising intellectual property. No blockbuster technology emerged from its stable of projects. In reality, the total amount of funding and the small size of projects mitigated against this. Optimal energy is a case in point – to bring a new vehicle to market requires the same order of magnitude of investment as to bring a new pharmaceutical drug to the market, namely USD 1 billion. The R300 million that went to the Joule was simply too little.

At macro level, the goals of the Innovation Fund, as stated in the White Paper and Deed of Trust, were attained. At meso- and micro-level they were not.

6.4 The R&D Tax Incentive

6.4.1 Context, overview and strategic objectives

The issue of tax incentives was covered fairly extensively in the NRDS. In particular, it proposed that "the DTI be given a mandate in consultation with SARS and the Treasury to pursue the development of tax incentives to strengthen the attractiveness and affordability of R&D in the South African setting relative to countries with which we trade and compete" (DST, 2002: 71).

The R&D Tax Incentive scheme was introduced in 2005 and has been operational since 2006. The goal statements of the scheme are stated in the introductory paragraphs to the annual Parliamentary reports[91] and are captured in the table below.

High-level objectives of the R&D tax incentive

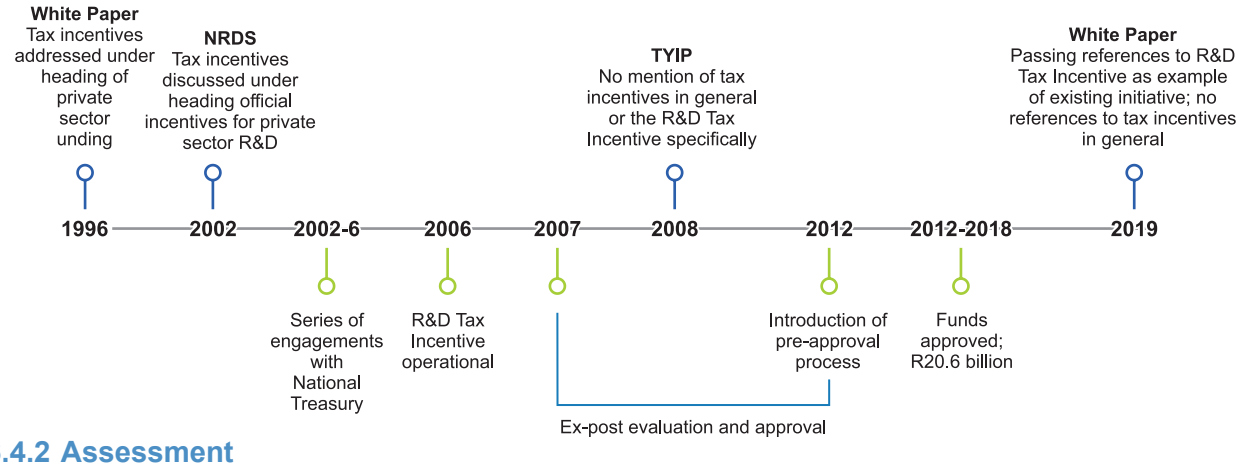
Strategic objectives	1	To encourage businesses to conduct scientific and technological R&D in South Africa
	2	To advance scientific knowledge and achieve technological advancement aimed at creating new or significantly improved materials, devices, products or processes
	3	To increase the positive spill-over to the rest of society through knowledge transfer and skills development

Over the period 2006-2016 the foregone tax revenue is estimated at R4.8 billion. The latter values peaked in 2010/11 but declined thereafter, the decrease being attributed to the administrative delays and backlogs associated with the pre-approval system (DST, 2019).

[90] DST. 2016. *Report of the Joint Government Industry Task Team on the Research and Development Tax Incentive.* Pretoria. Department of Science and Technology; DST. 2019. *Research and Development Tax Incentive Programme; Report to Parliament 2017/18.* Pretoria: Department of Science and Technology.

Key developments relating to the R&D Tax Incentive are captured in the figure below.

Timeline of implementation for the R&D Tax Incentive



6.4.2 Assessment

Assessment of the tax scheme-related activities and outcomes, as well as the metrics related to the R&D Tax Incentive, is provided in the tables below.

Assessment of the tax scheme-related activities and outcomes

	Activity		Comments
1	Develop and gazette the necessary legislation to support the scheme		There is a full summary of the necessary legislation with all the implementation steps in Table 1 of DST (2019).[93]
2	Develop the application process and accept applications		This process has been streamlined and the turnaround times reduced.
3	Undertake pre-R&D review/ screening and approval		This remains an area which requires further efficiencies, according to the World Bank report (2019).[94]
4	Undertake post-R&D review and approval of funds		This remains an area which requires further efficiencies, according to the World Bank report (2019).

Metrics relating to R&D Tax Incentive

Activity	Indicator	Initial value (2018)	Target value (year)
1	R&D expenditure supported	R3 billion	N/A
2	No. of participating companies[95]	902	N/A
3	No. of new applications	152	N/A
4	Approval turnaround	115	90 (2020)
5	Business R&D expenditure	R14.7 billion	R25 billion (2024)

Source: DST (2019)

The R&D Tax Incentive was introduced to counter systemic problems in the South African innovation system, namely the low level of private sector R&D, and the non-competitive position of the country versus its peer countries[96] in terms of the attractiveness and affordability of R&D. The incentive allows for a 150% deduction of the qualifying R&D expenses from taxable income, thereby reducing the cost of R&D by 14% (assuming a tax rate of 28%). It is generic in terms of sectors.

[92] DST. 2019. *Research and Development Tax Incentive Programme; Report to Parliament* 2017/18. Pretoria: Department of Science and Technology.
[93] DST. 2019. *Research and Development Tax Incentive Programme; Report to Parliament* 2017/18. Pretoria: Department of Science and Technology.
[94] World Bank. 2019. *Impact Evaluation of the R&D Tax Incentive in South Africa*. Washington, DC: World Bank.
[95] Since the incentive scheme was introduced.
[96] BRICS and middle-income countries

In terms of the administration, the pre-approval process has greatly improved the turnaround and overall administration of the scheme, and there are fewer complaints from the participating companies with respect to the overall process. On average, one new application is received by the DST every working day, and the turnaround time has been reduced to 94 days (the target is 90 days).

The introduction of the scheme has been a clear signal to the business sector that the government was placing strong emphasis on R&D. However, as noted earlier, the response has not been at the level which was hoped (World Bank, 2019). There is some evidence at the micro level of a positive response,[97] but it is clear that at the system level, business expenditure on R&D has remained static and, in some sectors, declined. Although exogenous issues such as business confidence and cost of capital also affect R&D expenditure, the effective adoption of the scheme is an important goal if the higher-level strategic objectives are to be realised. In particular, increasing levels of businesses expenditure on scientific and technological R&D, advancing scientific and technological R&D aimed at creating new or significantly improved materials, devices, products or processes, and increasing the positive spill over to the rest of society through knowledge transfer and skills development, are essentially unchanged since the introduction of the scheme and further sustained effort through the scheme and other forms of encouragement for business R&D remain important.

[97] James S. 2017. *Effectiveness of the Research and Development Incentive in Encouraging Research in South Africa.* Washington, DC: The World Bank Group; Walwyn DR & Naidoo S. 2019. Policy mixes and overcoming challenges to innovation in developing countries: Insights from a mixed methods study of South Africa's manufacturing sector. *African Journal of Science, Technology, Innovation and Development,* 11(6): 1-14.

Volume 4

REFLECTIONS AND RECOMMENDATIONS

CHAPTER 1

STRATEGY DESIGN

1.1 Reflections

This review was tasked to assess two system-wide strategic frameworks, the NRDS and TYIP, as well as the subsidiary strategies and interventions explicitly referenced in each. We referred to these two levels of assessment (or review) as Level 1 and Level 2 assessments, respectively. At each level, we undertook both a formative assessment – whether the 'units' of our assessments conform to good practice in strategy conceptualisation, design and implementation, and a summative assessment – what these strategies/interventions achieved in terms of outcome and impact. In this chapter we summarise our learnings with regard to formative assessment under the heading of 'strategy design'. We also make recommendations about how to improve on future strategic formulation and design. In the remainder of the volume, we reflect on the main learnings from our summative assessment of the individual strategies and interventions and what we recommend on this basis of these learnings.

1.1.1 Formative assessment of the NRDS and TYIP

Our formative assessment of the NRDS and TYIP was guided by six formative questions:

1. Has the strategy/plan been designed on the basis of a proper problem or needs analysis?
2. Are the goals and objectives of the strategy/plan clear and unambiguously formulated and is there an explicit theory of change?
3. Does the strategy/plan take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success?
4. Is the strategy/plan sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it?
5. Is the strategy/plan sufficiently clear about the resources (especially funding and infrastructure) that would be required to implement its various interventions to optimise success?
6. Does the strategy/plan specify how its progress and ultimate achievements and impact will be monitored and evaluated?

The first three questions are typically referred to as clarificatory evaluation questions (questions about context, conceptualisation and goals); the latter three questions are referred to as evaluability assessment questions (questions about the implementability, resourcing and

evaluability). Applying the principles of good strategy design to the NRDS and TYIP produced the assessment below. The resultant scorecard shows that both system-wide strategies fell short on most of the six criteria. The following formative assessment rating was applied:

- To a large extent addressed
- Not addressed or only in parts
- Poorly addressed or not addressed at all
- Moderately well addressed

		NRDS	TYIP
Clarificatory or design evaluation questions			
7.	Has the strategy/plan been designed on the basis of a proper problem or needs analysis?	To a large extent addressed	Moderately well addressed
8.	Are the goals and objectives of the strategy/plan clear and unambiguously formulated and is there an explicit theory of change which stipulates how (through which interventions, programmes, and initiatives) the expected outcomes and impact of the strategy/plan will be achieved?	Not addressed or only in parts	Moderately well addressed
9.	Does the strategy/plan take into consideration the specific contextual factors that may impact (positively and or negatively) on its anticipated success? Stated differently: is there evidence that the authors of the strategy/plan were aware of potential risk factors that may impact negatively on the achievement of strategies objectives?	Moderately well addressed	Not addressed or only in parts
Evaluability assessment			
10.	Is the strategy/plan sufficiently clear about agency and locus of responsibility for any subsidiary strategies and interventions that are included in it; in other words, is it clear who will take responsibility of specific strategies and be accountable for these strategies?	Moderately well addressed	Not addressed or only in parts
11.	Is the strategy/plan sufficiently clear about the resources (especially funding) that will be required to implement its various interventions to optimise success?	Moderately well addressed	Moderately well addressed
12.	Does the strategy/plan specify how its progress and ultimate achievements and impact will be monitored and evaluated (including indicators, targets and evidence of achievement)?	Poorly addressed or not addressed at all	Not addressed or only in parts

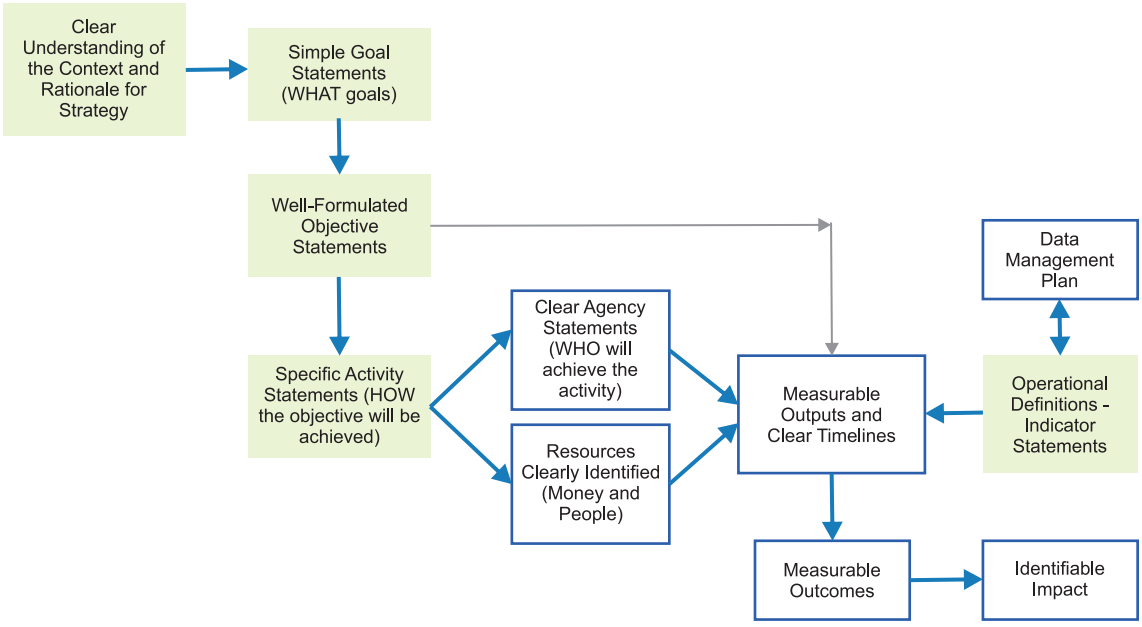
Our formative assessment of the **NRDS** concluded that insufficient attention was given to developing a well-constructed and explicit theory of change – the implicit theory of change is neither self-evident nor coherent. We also concluded that the description of outcome statements, setting of targets and technical description of indicators fell short of good practice in intervention design. With regard to the **TYIP**, we also concluded that the plan is weak as far as a theory of change is concerned. In addition, the core narrative of the TYIP is built around the imperatives of achieving a knowledge economy, but no attempt is made to show how the TYIP builds on the NRDS and gives expression to core challenges identified there. The focus on the five grand challenges as the means whereby South Africa would address its socio-economic problems was deemed to be a positive feature of the TYIP. However, as we will discuss in Chapter 6, the 'construction' and 'presentation' of the five grand challenges are uneven and do not conform to the standard logic of what grand challenges are. In addition, we also concluded that the M&E elements of the TYIP were lacking.

1.1.2 Assessment of the individual strategies and interventions

For the purposes of this review we applied a fairly standard template related to clarificatory evaluation, implementation evaluation and an assessment of outcomes for each of the 21 strategies and interventions identified. Given the large differences between these 'objects', the templates were not applied uniformly. In cases where a minimum level of adherence to good practice in strategy design and implementation was followed, it was possible to use these templates and reach appropriate conclusions. In some cases this did not apply and we were not able to make a definitive judgment about implementation or achievement.

Having said this, we found evidence of good practice in strategy design. The diagram below captures the basic steps in good strategy design.

Figure 1: Good practice in terms of strategy design



In our assessment, the strategies and interventions related to intellectual property constitute an example of good practice in strategy design, implementation and expected outcomes.

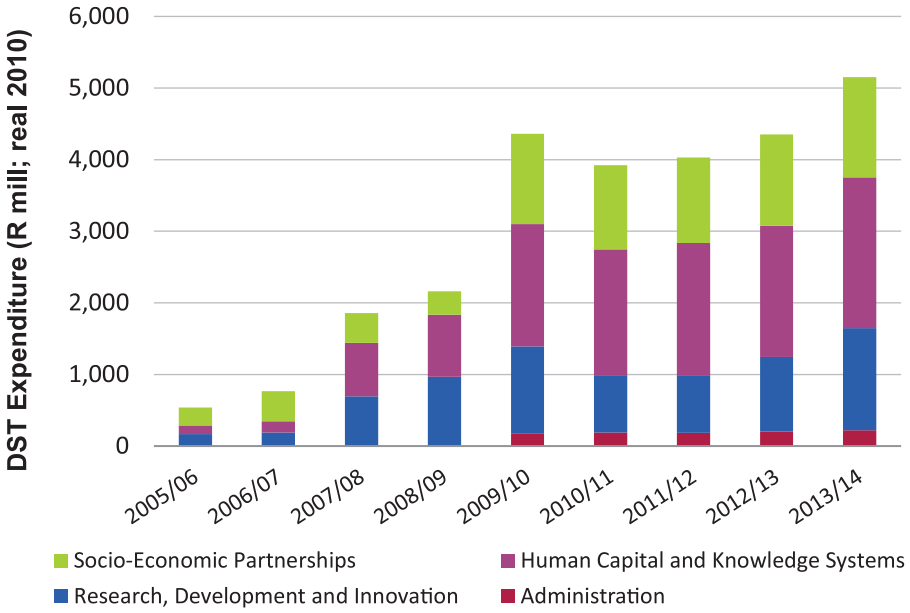
Illustrative example of good strategy design and implementation: Intellectual property

The NRDS and the TYIP were closely aligned on the issue of IP, and particularly the importance of establishing a suitable framework and enabling legislation for the effective management of IP arising from publicly financed research. As shown in the review, the intent of both documents with respect to building the necessary institutional capability has largely been realised. The legislation is in place, NIPMO has been established, Offices of Technology Transfer have been created at all public research institutes, and the national database covering IP arising from public-funded R&D has been created.

The successful realisation of these goals validates three broad principles which have been extracted from the reviews. In the first place, implementation of the IP strategy has been adequately resourced, both in terms of funding and people. The budget allocations have been significant, reaching R50 million per year for the foreseeable future. Securing this funding from National Treasury would never have been possible if the launch of the NRDS and TYIP had not coincided with growing government revenues and a massively increased DST budget as shown in Figure 2. The review of the White Paper on S&T noted that funding for the DST had increased considerably over the period 2006-2010, with nominal expenditure rising from R400 million in 2005/06 to R6.2 billion in 2013/14, an increase of over 900% in real terms (Walwyn et al., 2016: 58).[98]

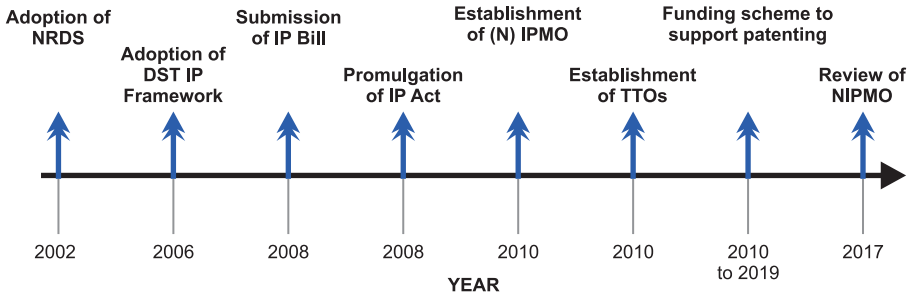
[98] Walwyn D, Bertoldi A, Kaplan D, Maharajh R, Manzini S & Motala E. 2016. *Review of the White Paper on Science and Technology.* Pretoria: National Advisory Council on Innovation.

Figure 2: DST budget (2005/06-2013/14) in real terms (2010 ZAR)



The second general principle is that the implementation was guided by a sub-strategy covering only IP. Both the TYIP and the NRDS were framed as high-level documents with little of the necessary detail for successful policy implementation. The 2006 IP framework[99] (effectively an IP strategy) provided a clear structure for the implementation of the policy intent, with a number of sub-goals and output indicators. Such a step, namely the development of a more detailed implementation plan for a specific policy goal within a high-level document, is essential for successful implementation. The highly structured approach to the IP intent is shown in Figure 3.

Figure 3: Timeline for implementation of the IP policy intent



Finally, the IP strategy was successful because it only needed the support of the DST to be implemented (even though it over-emphasised patents and did not devote sufficient attention to 'secondary' areas such plant breeders' rights, designs and trademarks). Although the dti has a responsibility for IP management, it does not have any mandate in terms of public-funded R&D. The latter remains a DST-specific mandate, which allowed the Department to proceed without the complexity of negotiating the terrain of overlapping responsibilities. Such exclusivity was not encountered in other areas such as the R&D Tax Incentive, energy or resource beneficiation. In summary, the intent of the TYIP and NRDS on IP has been successfully implemented because it has been adequately funded, it has been clearly structured, and it has been a direct DST responsibility. The broader question as to whether the policy has 'worked' is another matter.

[99] DST. 2006. *Intellectual Property Rights (IPR) From Publicly Financed Research Framework*. Pretoria: Department of Science and Technology.

Examples of poor strategy design and implementation

Our review also revealed many cases where the 'rules' of good practice in strategy design were not followed. The detailed discussion is found in Volume 3 and in our analyses of each strategy in Volume 5. We suffice here with an example of one (bad) practice that we found in many cases; namely, the relationship between a strategy and its implementation plan (or roadmap).

Good practice in strategy design dictates that the formulation of a strategy (with clear goals, objectives, an explicit theory of change and expected outcome statements) should be followed by a clear and concrete implementation plan. Such as plan is an operational version of a strategy, and specifies clearly how the strategy will be implemented: what resources are required, who are the responsible actors that will deliver the strategy within what timelines, clearly stated deliverables, targets, and explicit performance and outcome measures or indicators. In an ideal world, a strategy is followed fairly quickly by an implementation plan. The latter effectively becomes the project management framework for the strategy. In order to illustrate this point for the purposes of this discussion, we have selected the timelines from three of the science missions as per the figures below.

Figure 4: Illustrative example 1: Timeline of developments relating to the astronomy strategy

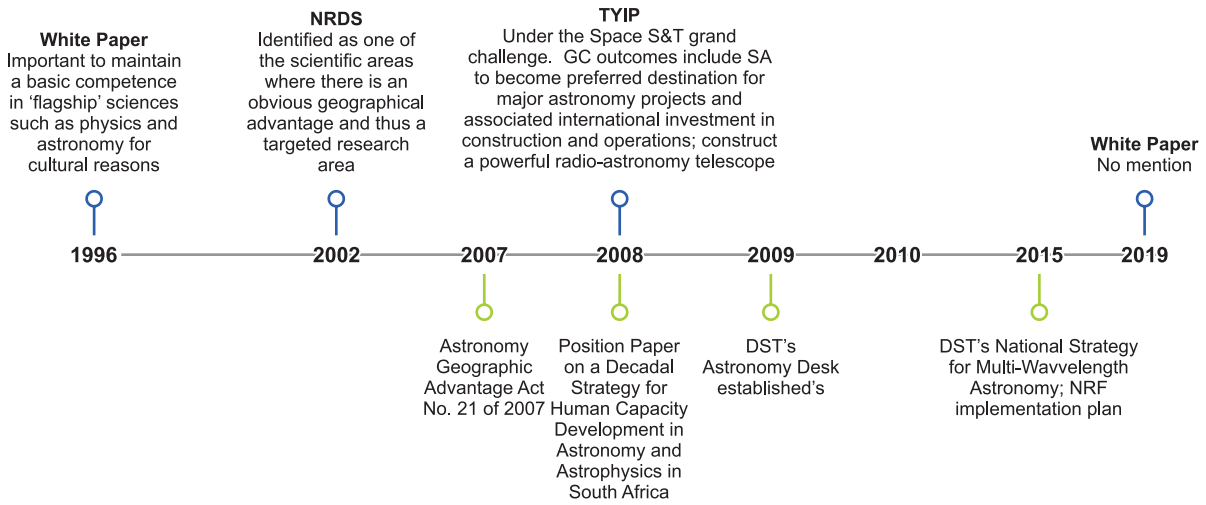


Figure 5: Illustrative example 2: Timeline of developments relating to the palaeosciences strategy

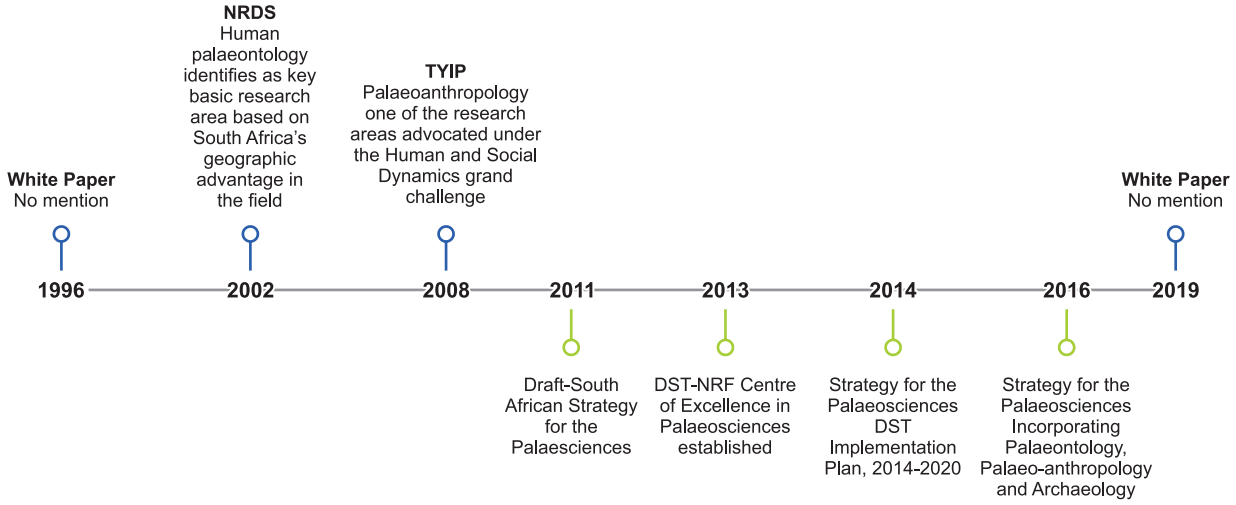


Figure 6: Illustrative example 3: Timeline of developments relating to the marine and antarctic strategy

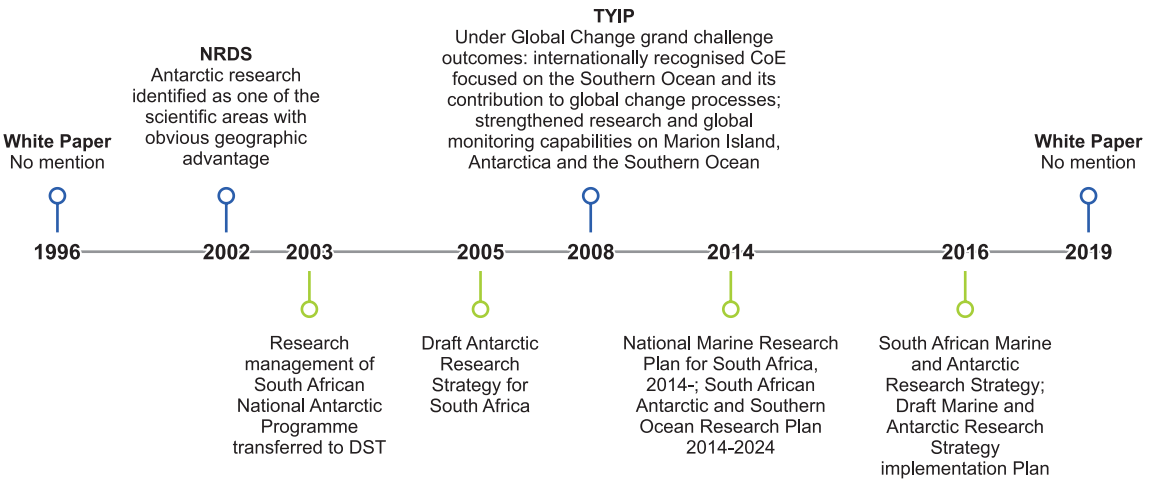


Table 1: Comparative assessment of timelines in designs of three strategies

	Astronomy	Palaeosciences	Marine and Antarctic science
Time lag between first mention in NRDS and formulation of strategy	13 years	9 years (to draft strategy)	3 years
Time lag between publication of strategy and implementation plan	No implementation plan found	3 years	9 years
Correct sequence of strategy followed by plan	No	Yes	No: 2014 Antarctic and Southern Ocean Plan precedes the 2016 strategy

Similarly reconstructed timelines for other strategies reveal many of the same 'fault lines':

- Long delays in moving from formulating a strategy to an implementation plan;
- In some cases, we could not identify or locate an implementation plan (although occasionally we found a PowerPoint of an implementation plan); and
- In the more complex cases (such as marine and antarctic sciences), the timeline shows a lack of a clear and linear path from strategy to implementation (and in some cases to M&E).

There are many possible reasons why individual strategies failed to conform to the basic rules of good strategy design and implementation, for example:

- Lack of clarity of ownership of the strategy – which would be a definite possibility in the case of multi-actor and multi-departmental interventions;
- Lack of leadership and 'championship' that would drive the implementation of the strategy;
- Lack of resources (lack of continuity in human resources and inadequate financing); and
- Lack of appropriate expertise and capabilities in the design of strategies and their implementation plans.

But it is also important to emphasise that our review reveals that some strategies and interventions were implemented despite the absence of an explicit (and updated) implementation plan (which we established through an analysis of the annual expenditures and disbursements of the DST, dti and other agencies). We also found evidence that strategies and implementation plans were often rewritten (with changes in the formulation of strategic objectives, outcome areas and indicators) as time progressed. This is not surprising and can even be described (somewhat cynically though) as 'good' project management when interventions are adjusted to changing circumstances. However, even in such cases, good practice in strategy design would dictate that fundamental revisions in strategic goal and objective statements should be informed by regular performance monitoring and evaluation studies. It is not clear to us that this was always the case.

1.2. Recommendations

Recommendation:
Institutionalise good practice in appropriate strategy design and implementation

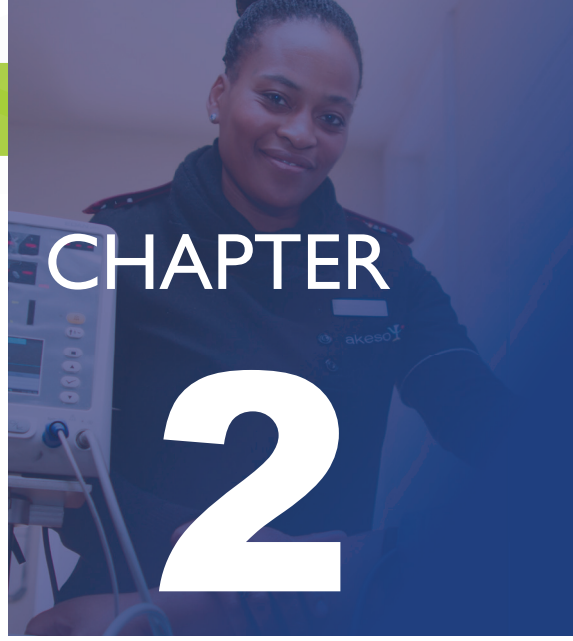
In the formulation of future strategies and implementation plans, good practice in intervention design needs to be adhered to. Within the present environment of fiscal constraints, policy objectives without allocated budgets – even if these have to be obtained through the re-direction of existing allocations – will be meaningless. Full attention needs to be given to how each policy objective will be funded and resourced. As far as possible, focus should be placed on objectives which have a linear and single-department theory of change. Initiatives which require significant inter-departmental agreement and cooperation, and particularly negotiations on areas of control, are complex to navigate and have a high rate of failure. Impact areas within which the variables have a non-recursive relationship (in other words, bidirectional causality) are similarly complex, and sustainable change will only be evident over long time periods (such as the impact of IP legislation on the output of technology-intensive industry). Our formative assessment has revealed many examples of poor formulation of strategic goals and objective statements, as well as widespread confusion between goals and objectives and between outputs and outcomes. It is strongly recommended that all future strategies and plans devote dedicated attention to explicit theories of change, with clearly defined short- and medium-term objectives and outcomes.

Recommendation:
The design of new strategies and plans must meet the criteria of feasibility and risk assessment

Key requirements of strategy design pertaining to the implementability and feasibility of an intervention need to be met. This implies that more attention should be given to agency (locus of responsibility) and resource estimates (budgets and infrastructure) and timeframes. In addition, a well-designed strategy must make reference to possible risk factors that can constrain or even invalidate its proper implementation.

Recommendation:
Strategic plans must adhere to good practice in the setting of targets and the construction of appropriate performance and outcome indicators

We have commented throughout our review, but especially in our summative assessment of the NRDS and TYIP, on the many instances of inappropriate and unrealistic target-setting. Such practice means that the authors of these strategies did not search properly for supporting evidence in setting appropriate and realistic targets. In addition, insufficient attention is given to the distinction between qualitative and quantitative (statistical) indicators, as well as to the availability of data to populate indicators.



CHAPTER

2

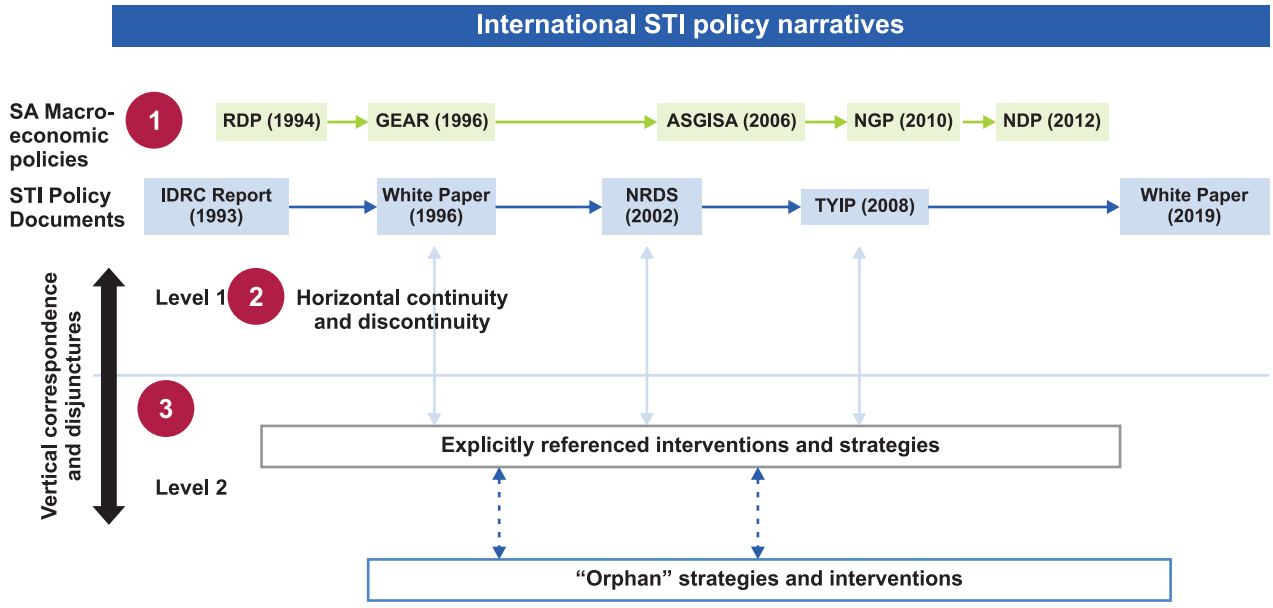
STRATEGY IMPLEMENTATION: ON CONTINUITIES AND DISJUNCTURE'S

2.1 Introduction

One of the objectives of this study was to reflect on the nature and extent of continuities and discontinuities in STI-policy making over the past 20 years. We have unpacked this aim into three issues as per below (see Figure 7):

1. What was (and is) the degree of correspondence between the South African STI policy documents and the macro-economic policies of the government over this time period?
2. What is the extent of the 'horizontal' continuity or discontinuity between the 1996 White Paper, the NRDS and TYIP, and the 2019 White Paper?
3. What is the extent of the correspondence (or disjuncture) between the NRDS/TYIP and the subsidiary strategies and interventions?

Figure 7: Analysing continuities and discontinuities in STI policy

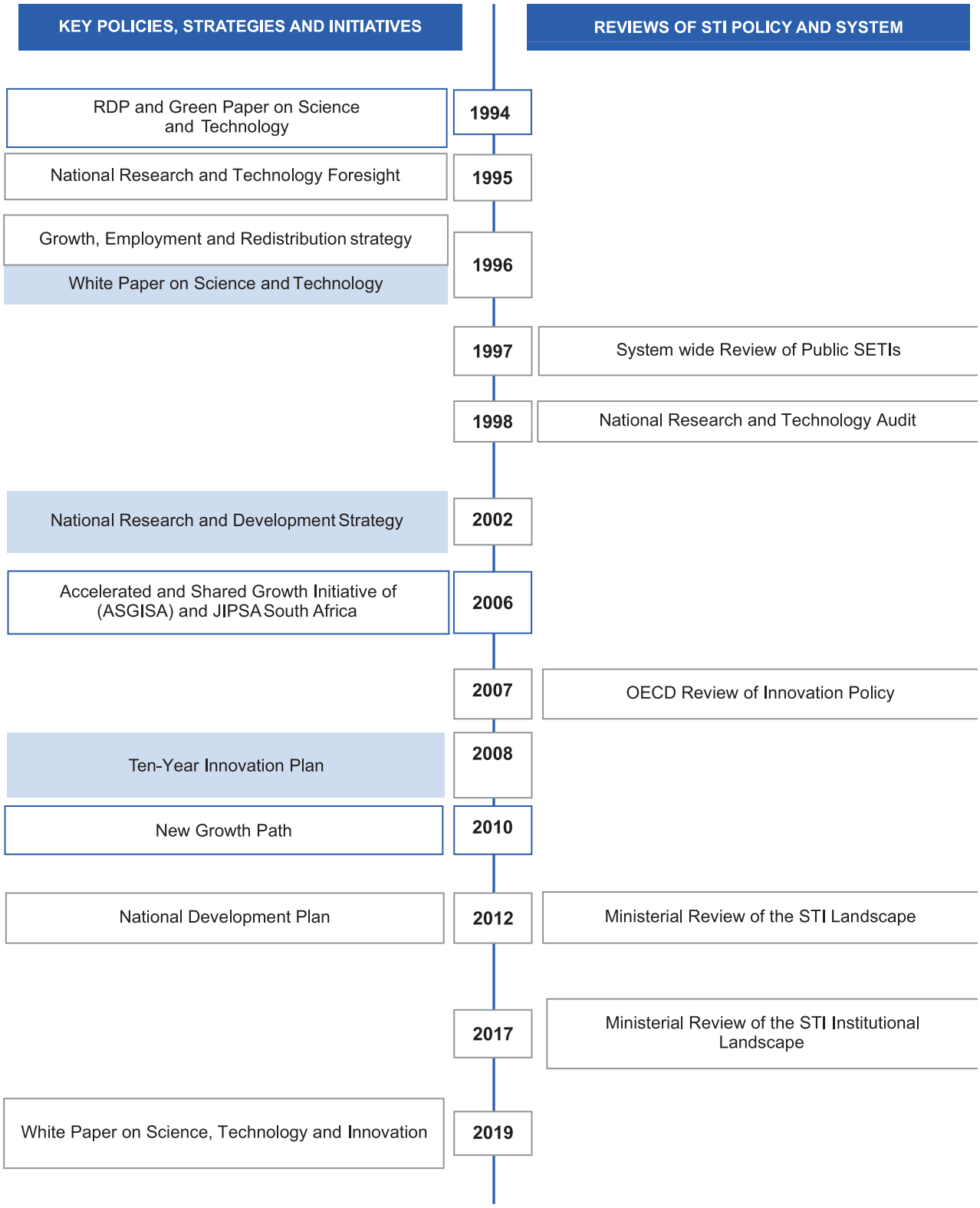


2.2 Correspondence between the STI policy documents and the macro-economic policies of the government over this time period?

Responding to this question systematically and in detail is beyond the scope of our review as it would require a retrospective analysis of all relevant policy documents, interviews with key actors (many who are no longer available), but also importantly a good understanding of the political economy of the STI system of the past two decades. At one level, the answer to the question of the correspondence between the these STI policies and other macro-economic policies as a straightforward 'yes' as these policies would not otherwise have been endorsed by their Cluster, the Forum of South African Directors-General or Cabinet.

However, our response to the question will be limited to the explicit references in the STI policy and strategy documents to macro-economic policies of the day. Before we do this, we present a visual timeline of these various documents as well as system-wide reviews of the time:

Figure 8: Historical timeline of STI and other policies and plans (1994-2019)



The NRDS and TYIP formed part of the ongoing policy-making process to address strategic national challenges in post-apartheid South Africa. Both documents are embedded in a long series of macro-economic and industrial policies that emerged after the publication of the RDP in 1994. The NRDS itself does not make explicit reference to either of the two macro-economic policy documents that preceded it (the RDP or GEAR). As discussed in Volume 2 (Chapter 2), the authors of the NRDS referred extensively to the main policy intents and imperatives of the 1996 White Paper on S&T and how the NRDS would address these. At around the time that the TYIP was being drafted (in 2006), the government introduced a third macro-economic policy (to

follow the RDP of 1994 and GEAR in 1996), namely the Accelerated and Shared Growth Initiative for South Africa. AsgiSA was the result of concerns about GEAR and narrowly conceived black economic empowerment excluding potential beneficiaries resulting in the capture of policies and programmes of government. AsgiSA was not, however, wholly embraced by all constituencies. Hence, sectors recrafted their putative plans in the new 'policy' language, which included 'shared' and 'inclusive'. Two years after the TYIP was published, the New Growth Path – which had its origins in the labour movement (and not fully endorsed by business and government) – was accepted as macro-economic policy.

Both of these policy framework evolutions (AsgiSA and NGP) were, however, subsumed under the internal coup whereby Mbeki was replaced by Zuma. That also inaugurated the National Develop Plan (2012) as the fourth iteration of macro-economic policy in the country. It is well known that the S&T section in the NDP was not written by the DST but rather by Malegapuru Makgoba.

Returning to the TYIP, it seems clear that three main considerations influenced the thinking behind the drafting of the Plan: the conclusions of the OECD's 2007 review of South Africa's innovation policy;[100] the imperative of the recently adopted AsgiSA policy framework; and learnings from international STI policy developments in the European Union around grand challenges.

The 2007 OECD Review assessed the extent of system coordination through a four-level model of policy coordination. It found that while there were mechanisms for cross-departmental coordination at level 2 (the cluster system), there was no such facility at the highest level of government (level 1), nor any means to effect prioritisation (OECD, 2007: 12). In effect, the Review claimed that the South African system of innovation was only loosely coordinated. In 1994, South Africa emerged from a period where there had been attempts at central coordination in the form of 'grand apartheid' and the later State Security Council. Post-1994, attempts to install central coordination – as in the Ministry for the RDP, the subsequent role of Treasury in promoting GEAR, and the present difficulties that the 'adoption' of the NDP is evincing – suggest a resistance to central coordination from many quarters.

The introductory paragraphs to the TYIP provide evidence that the DST took the conclusions and recommendations of the 2007 OECD Review seriously. It acknowledged that "the NSI must become more focused on long-term objectives. In particular, the government must urgently confront the failure of the NSI to commercialise the results of scientific research. The DST's conclusions in this regard are mirrored in a peer review conducted by the Organisation for Economic Cooperation and Development (OECD)" (DST, 2008: 2).

In the same paragraph, the authors indicate that the overall goals of the TYIP are commensurate with AsgiSA (ibid.):

> *The economic cluster of government departments, which includes the DST, has identified a number of key national targets to meet over the decade leading up to 2018. These include achieving 6 percent economic growth by 2010 a core target of the Accelerated and Shared Growth Initiative for South Africa (ASGISA) – and halving poverty and unemployment by 2014. The Ten-Year Innovation Plan helps to map this critical trajectory and supports the National Industrial Policy Framework (NIPF) by encouraging sectoral growth to enhance the competitiveness of the economy. South Africa's prospects for improved competitiveness and economic growth rely, to a great degree, on science and technology. The government's broad developmental mandate can ultimately be achieved only if South Africa takes further steps on the road to becoming a knowledge-based economy, in which science and technology, information, and learning move to the centre of economic activity.*

In the final paragraph on the same page, the authors of the TYIP emphasise that this is not yet another short-term plan, but a much more forward-looking framework that has, as point of departure, what strategic outcomes need to have been achieved by 2018. These strategic outcomes are identified as the 'grand challenges'.

As indicated above, before the AsgiSA policy could be taken further, President Thabo Mbeki was replaced by Jacob Zuma as President and, in sequence, three new economic policy documents appeared: The New Growth Path in 2010, the dti's Industrial Policy Action Plan (IPAP) in 2011, and the overarching NDP in 2012.

[100] OECD. 2007. OECD Reviews of Innovation Policy: South Africa. Paris: Organisation for Economic Cooperation and Development.

In common with the vision statements of many other countries, the NDP, or Vision 2030, identified STI as key pivots for achieving a more inclusive society (NPC, 2012: 93):[101]

> *Science and technology are the differentiators between countries that are able to tackle poverty effectively by growing and developing their economies, and those that are not. The extent to which developing economies emerge as economic powerhouses depends on their ability to grasp and apply insights from science and technology and use them creatively. Innovation is the primary driver of technological growth and drives higher living standards.*

As such, the NDP gives much stronger prominence to STI than the earlier RDP had done. Most importantly, the Plan adopts a system view of the interrelationships among STI and broader societal influences. In short, it advocates the innovation systems approach (ibid.: 325):

> The system of innovation has a key role to play. It is the principal tool for creating new knowledge, applying knowledge in production processes, and disseminating knowledge through teaching and research collaboration … The national system of innovation is about networks and partnerships. Research and development happens in many sites outside universities, including the science councils, state-owned enterprises and industry.

This was an important development, given the observation of the 2012 Ministerial Review Committee that the innovation system concept appeared to lack currency beyond the walls of the DST. If we fast forward to the 2019 White Paper, it is clear that the NDP has assumed new authority. In the opening pages of the White Paper the following is stated (DST, 2019: x):

> *More than 20 years after the adoption of the 1996 White Paper on Science and Technology, South Africa needs an updated STI policy – for two main reasons. Firstly, while reviews show good progress in the implementation of the 1996 White Paper, South Africa has not yet fully benefited from the potential of STI to advance the objectives of the National Development Plan (NDP). To illustrate, the STI institutional landscape has been expanded and there has been a threefold increase in publications, significant growth in the participation of black people and women in the research and development (R&D) workforce, and a rise in doctoral graduation rates. However, challenges remain. The NSI is still not fully inclusive, and since 1996, South Africa's innovation performance (measured in patents and products) has been relatively flat. Secondly, as the world is rapidly becoming more technologically advanced, new STI policy approaches are required to respond to the opportunities (such as rapid economic growth) and threats (such as the loss of some traditional jobs) of such change.*

In the remainder of the White Paper, the NDP is referred to no less than 25 times. In fact, a whole section (1.1.2) is devoted to a discussion of the "the role of STI in the NDP". The insistence in the White Paper on the alignment of the policy intents with the overarching goals of the NDP means – even if only at a rhetorical level – that the NDP has become the de facto national policy frame for STI in the country.

2.3 Horizontal continuities and discontinuities

There is an obvious sense in which successive STI policy documents in a country would reflect minimal levels of continuity in terms of the issues that they address. Although STI policies and strategies will change over time in terms of shifts in emphasis and focus because of the underlying changes in the nature of STI systems, one expects such policies and strategies to address issues related to system governance, policy formation and coordination; framework conditions; the advancement of science, technological development and innovation; STI institutional arrangements; business and innovation support initiatives; and monitoring and evaluation frameworks and measures. These 'themes' are captured in various models of the STI system which, in turn, are informed by different theories and models of science and innovation.

Our discussion here is devoted to a discussion of two main *continuities* and one main *discontinuity* between the NRDS and TYIP.

[100] OECD. 2007. OECD Reviews of Innovation Policy: South Africa. Paris: Organisation for Economic Cooperation and Development.

The first explicit and recurring continuity between the 1996 White Paper, the NRDS and TYIP relates to the rhetoric of the idea of a *'national system of innovation'*. Beginning with the introduction of the concept of the 'NSI' in the White Paper in 1996, it becomes a pervasive feature of both the NRDS and TYIP and most subsequent STI documents (including in many of the subsidiary strategies).

The second continuity – less explicitly voiced – concerns the strong commitment to the linear model of innovation in both the NRDS and TYIP. This commitment is evident at a number of levels – from the explicit recurring rhetoric of the 'innovation chasm' to the use of standard Frascati-type metrics that reflect the institutionalisation of the linear model at the OECD since the 1960s. But it is also, as we comment later in this section, evident in the thinking around S&T missions in both the NRDS and TYIP.

At face value, these two narratives should not easily co-exist – at least not in terms of the standard theories of innovation. However, as we will argue, the 'adoption' of the notion of a national system of innovation as a central heuristic framework in these documents is mostly rhetorical and does not correspond with the reality of the development of the South African STI system over the past two decades.

The first discontinuity refers to the level of system performance measurement. We have already referred to this indirectly in our discussion in Volume 2 (Chapter 3) on the indicators that were included in the NRDS and TYIP. In that discussion we pointed out that there was an inadequate understanding of the requirements in constructing appropriate system-level indicators that can be employed in a continuous manner to measure the performance of the STI system. We elaborate on this topic in Chapter 4 of this volume where we present our final reflections and recommendations relating to M&E.

2.3.1 The rhetoric of the national system of innovation

South Africa's White Paper on S&T not only introduced the idea of the NSI, but also scoped out the attributes that it should meet in addressing national development. The White Paper followed the 1993 IDRC review of the country's S&T policy at the time. In its review of the South African STI system, the Academy of Science of South Africa writes as follows (ASSAf, 2013: 37):[102]

> *Mission leadership and the main technical advice for the White Paper came in the person of a former Chair of the OECD Science and Technology Policy Committee so that much of its thinking aligns with the mainstream of OECD thinking of that time. The White Paper offers what might be termed a catholic definition of the national system of innovation "as a set of functioning institutions, organisations and policies which interact constructively in the pursuit of a common set of social and economic goals and objectives" (DACST, 1996: 20). To enable such interaction, the White Paper laid out the government role in policy formulation and regulation, provision of funding to promote research and innovation, ensuring mechanisms for technology transfer, intervening in cases of market failure or direct national need, human resource development and capacity building and the provision of infrastructure. In addition, it argued for the use of foresight and forecasting methods to inform priority setting, and for the system as a whole to be subject to performance measurement to ensure accountability and transparency. These principles were and are consistent with the best practices outlined above.*

In a paper published in 2013, Michael Kahn argued that the initial introduction of the NSI concept in the STI space was commensurate with similar 'moves' made across the public sector by a democratic government that wanted to emphasise the difference between the apartheid and post-apartheid eras (Kahn, 2013):[103]

> *In response to the IDRC Mission and other policy processes, notably the Science and Technology Initiative (STI), the new Department crafted a Green Paper on S&T, followed by a White Paper (DACST 1996). … The White Paper then made the seminal proposal to adopt the innovation systems approach. This was in keeping with a government-wide attempt to distance the new dispensation from the Apartheid past. This distancing naturally involved both symbols (new national flag, national anthem, national crests) and rhetorical devices….. The White Paper (DACST, 1996, p. 19) asserted that the use of the concept of a national system of innovation as a framework for policy is an attempt to signal a radical departure from the current situation and understanding in South Africa, introducing a new view of the role and status of the sciences, engineering and technology in national development' and went on to assert that 'A well-managed and properly functioning national system of innovation will make it*

[102] ASSAf. 2013. *Review of the State of the Science, Technology and Innovation System in South Africa*. Pretoria: Academy of Science of South Africa.
[103] Kahn MJ. 2013. Rhetoric and change in innovation policy: The case of South Africa. *Science, Technology and Society,* 18(2): 189–211.

possible for all South Africans to enjoy the economic, socio-political and intellectual benefits of science and technology.' (p. 189)

In his assessment of the South African science system, Kahn (ibid: 200) concludes:

> *It has been shown that small changes aside, the post-1994 innovation system demonstrates institutional continuity with its predecessor. The same set of public research organisations remain; the underlying thrust of innovation policy remains squarely on supply side measures through which scientists decide on priorities and are funded accordingly. The main change has been demographic. Where the IDRC Review had castigated Innovation System 1.0 as uncoordinated and fragmented, Innovation System 1.1 might be criticized for being even more so. Nor did the 'new' innovation system directly address the housing, energy, electrification needs that IDRC had identified. The innovation system did not generate major innovations that captured public attention, aside from numerous products for the mobile telephony and digital TV industries. Patenting remained at around 100 per year, reflecting the lack of growth in high-tech exports, while SASOL displaced CSIR as the leading institutional patentee. Cumulative investments in the order of ZAR 3 billion made through the Innovation Fund and Biotechnology Regional Innovation Centres gave rise to no major breakthroughs. The attempt to enter the electric vehicle market with the Joule battery-powered car yielded a comely body, but no market interest. The ZAR300 million investment came to nothing. Considerable skill was evident in the building of the SA Large Telescope and in preparing a bid for the USD 2 billion Square Kilometre Array. In May 2012 South Africa and Australia became joint awardees of the project. In effect the large pre-1994 military missions were replaced with 'big science'.*

His concluding assessment (after discussing the findings and recommendations of the 2012 of the Ministerial Review) are equally harsh (ibid: 207):

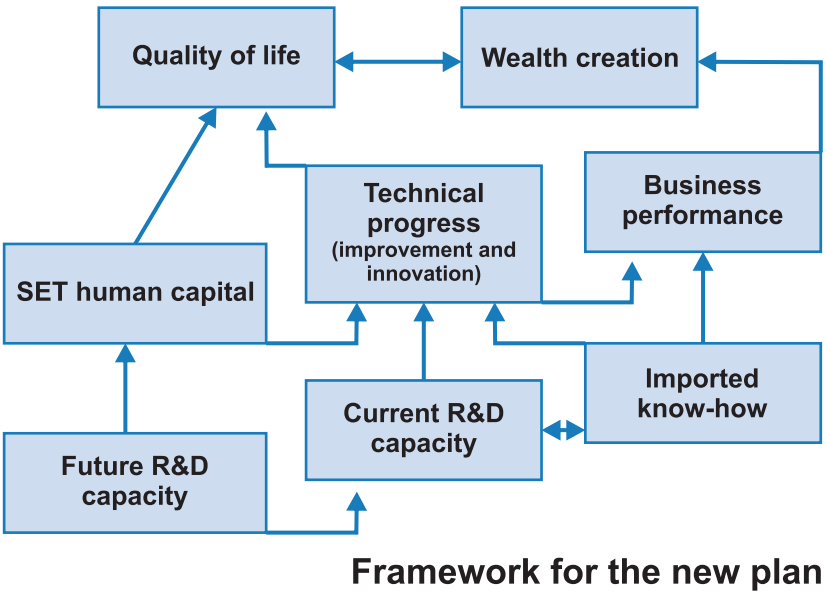
Despite rhetorical adherence to the innovation systems approach policy remained fixed on supply side measures consistent with the linear model of innovation. The CSIR, one of the loci of linear model thinking has remained a core institution of the innovation system and continues to exercise strong influence on policy formulation and implementation. Much institutional change in the innovation system has been superficial and involved reconfiguration rather than change of focus. The IDRC Review of 1993, the 2007 OECD Review and the Ministerial Committee of 2012 agree on this continuity and the lock in of linear model thinking. In addition, the focus on the individual scientist rather than research group inadvertently promotes extractive behaviours. These are the underlying reasons that explain the continuity.

In a nutshell, the argument is that the prominence afforded to the notion of a 'national system of innovation' in the White paper, NRDS and TYIP was mainly a rhetorical device (and hence more aspirational than actual) in order to emphasise the difference between the post-apartheid STI system and the 'fragmented' apartheid science system. Kahn's conclusion is that very little of the initial promise of developing an NSI would be realised. The reality is that the more dominant understanding of innovation in the NRDS and TYIP is that of the linear model of innovation.

2.3.2 The commitment to the linear model of innovation and the notion ('myth') of the innovation chasm

In our discussion in Volume 2: Chapter 1 of the implicit theories of change in both the NRDS and TYIP, we showed how prominent the linear model of innovation is in both documents. This is graphically illustrated in the NRDS as in Figure 9 below.

Figure 9: Framework for the NRDS



Source: DST (2002: 26)

In his comments on the NRDS, Kahn notes the following about this diagram (ibid: 198):

> *The upward arrows from R&D activity toward the central block 'technical progress—improvement and innovation,' amount to endorsement of the linear model of innovation. This formulation is consistent with the earlier White Paper emphasis on the importance of technology diffusion, especially of 'available knowledge' for technological change. This is surprising, coming but six years after the adoption of the 'innovation systems approach' and shows the continued dominance of a science-led approach to innovation, an approach that was dominant in Western economies in the 1960s and 1970s, but that gave way in the 1980s to the formulation of the interactive system model. The rhetoric of the innovation systems approach and policy implementation was found wanting.*

Kahn makes a similar comment on the commitment to the linear model in the TYIP six years later (ibid: 202):

> *Returning to the Ten Year Plan, this continued with linear model thinking in arguing that wealth creation depended on increasing R&D expenditure and know- ledge outputs, with a target of GERD: GDP of 2 per cent by 2018. The Plan saw progress being driven by four elements:*
>
> - *Human capital development.*
> - *Knowledge generation and exploitation (R&D).*
> - *Knowledge infrastructure.*
> - *Enablers to address the 'innovation chasm' between research results and socioeconomic outcomes.*

The second and fourth bullets are classic linear model thinking. As is known from innovation survey evidence, most firms do not conduct in-house R&D; most firms gain their ideas for innovation from other firms; and non-technological innovation is as important as technological innovation (Blankley and Moses, 2009). These perspectives, all available from the National Innovation Survey 2002–2004, are absent from the 'Innovation' Plan.

In an earlier paper (2008), Jafta and Boshoff[104] reached the same conclusion. They quote Caracostas (2007)[105] in this regard as follows (Jafta & Boshoff, 2008: 6):

[104] Jafta R & Boshoff W. 2008. A*chieving AsgiSA's Aspirations: The role of the national system of innovation*. TIPS Forum Paper. Cape Town: TIPS.
[105] Caracostas P. 2007. The policy-shaper's anxiety at the innovation kick: How far do innovation theories really help in the world of policy? In F. Malerba & S. Brusoni (Eds.), *Perspectives on Innovation*. Cambridge: Cambridge University Press, pp464-489.

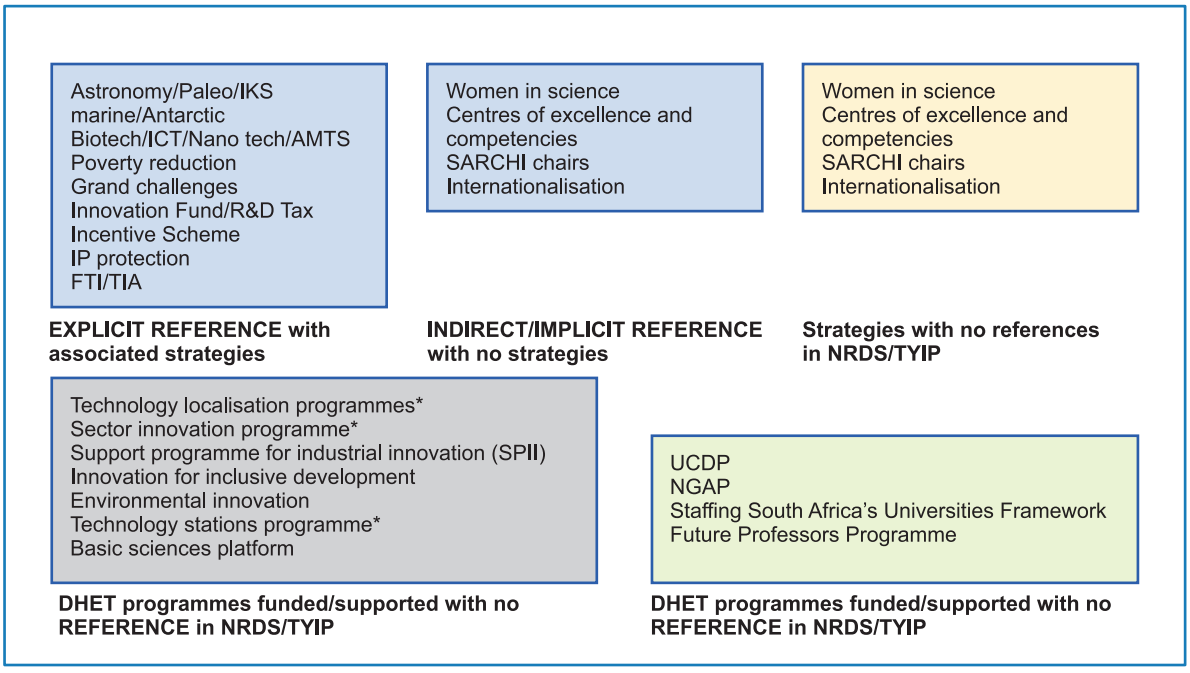
Whether he or she likes it or not, a policy-shaper trying to defend the need for more funds for R&D relies implicitly on the famous 'linear model of innovation'. The view of innovation sees the relations between research and the market as forming a 'chain', a straight line extending from research to market ('technology push') or from market to research ('technology pull'). Despite the fierce criticism they have attracted from the more popular systemic approaches, these linear models paradoxically continue to influence thinking amongst decision-makers and public opinion because they have the virtue of being simple (or appearing to be so).

A corollary of the acceptance of the linear model of innovation was the introduction and adoption of the notion of the 'innovation chasm': initially in the NRDS in 2002, but later in many subsequent policy documents. The concept of the innovation chasm is widely referred to by the DST, as well as by TIA, the National Intellectual Property Management Office (NIPMO) and the CSIR.[106]

2.4 Vertical coherence and disjunctures

Our discussion now turns to the extent of the coherence or otherwise between the two strategy-wide frameworks (NRDS and TYIP) (Level 1) and the 'subsidiary' level of strategies and interventions (Level 2). In our discussion in Volume 1 (Chapter 3) we presented the following diagram, which captured our process of identifying which strategies and interventions we needed to include or not in our review.

Figure 10: Classification of strategies and interventions in NRDS and TYIP



In addition to acting has a heuristic classification framework for the selection of strategies and interventions to be reviewed, the resultant 'classification' is also useful for our current discussion that focuses on the different possible configurations of correspondence or disjuncture between Levels 1 and 2. From this perspective there are four theoretical possibilities:

1. Close correspondence between Level 1 and Level 2: There is an explicit reference to a strategy in the NRDS/TYIP to be developed which corresponds with a subsequent strategy/intervention (and often also an implementation plan).
2. Loose correspondence between Level 1 and Level 2: There is only an implicit (even passing) reference to a strategy or programme which corresponds either with an existing intervention or programme or one that is subsequently developed.

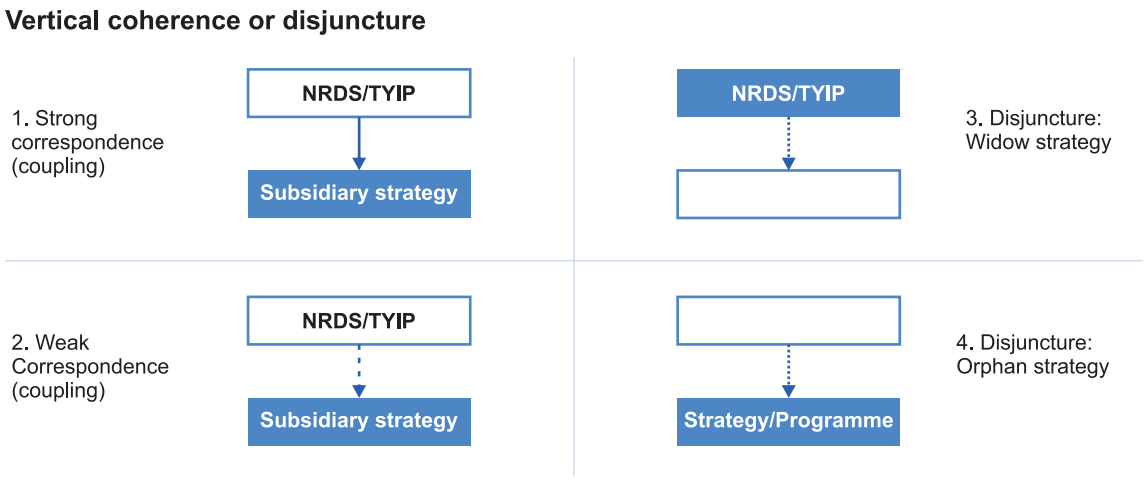
[106] Kaplan D. 2008. Science and technology policy in South Africa: Past performance and proposals for the future. *Science, Technology and Society,* 8(2):235–260; Pouris A. 2008. *Science-Industry Relations and the SA Innovation Chasm: Searching for lost technologies.* Pretoria: Department of Trade and Industry.

3. Widow strategies: There is an implicit reference to an initiative or programme in the NRDS/TYIP but with no corresponding strategy at Level 2.

4. Orphan strategies: There is no reference to a specific strategy or intervention in the NRDS/TYIP but there is a strategy or programme which is implemented and funded as a distinctive intervention.

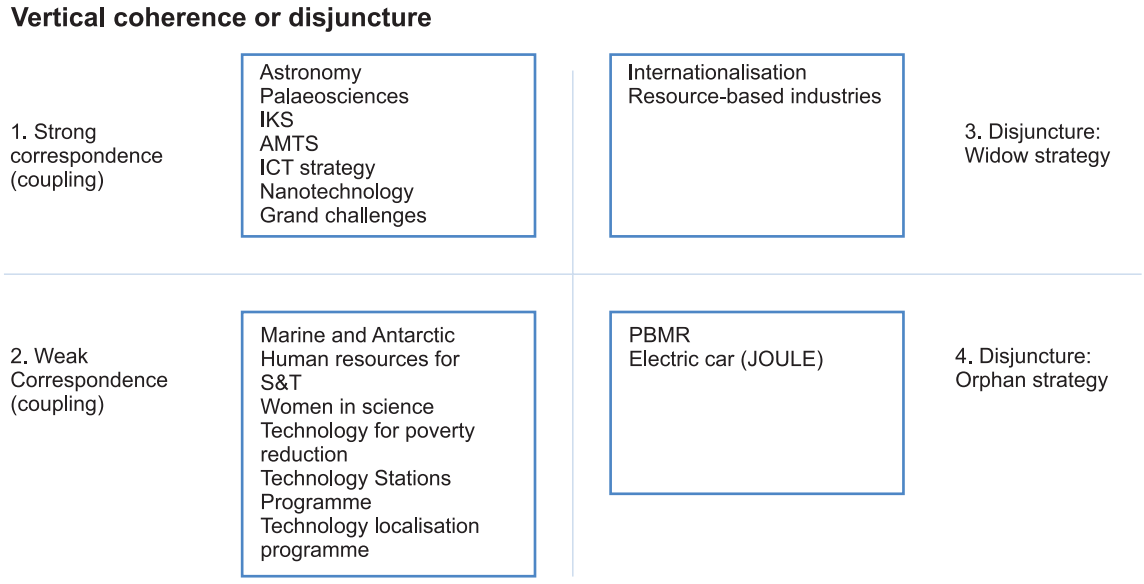
We can represent these four possibilities as per Figure 11 below.

Figure 11: Visualisation of vertical coherence or disjuncture (basic framework)



When we populate this framework with actual strategies and interventions we get the following:

Figure 12: Visualisation of vertical coherence or disjuncture (with examples)



In his assessment of South Africa's S&T policy in 2008, David Kaplan[107] makes reference to two examples of 'poor articulation' between identified priorities and actual implementation – both referring to technology missions, and both of which had been previously identified in the 2007 OECD Review of SA's innovation policy (Kaplan, 2008: 13):

As outlined earlier, the OECD assessment was that two of the four technology missions prioritized

[106] Kaplan D. 2008. Science and technology policy in South Africa: Past performance and proposals for the future. *Science, Technology and Society,* 8(2):235–260; Pouris A. 2008. *Science-Industry Relations and the SA Innovation Chasm: Searching for lost technologies.* Pretoria: Department of Trade and Industry.

in NRDS had not been implemented. The mission to develop technology and knowledge to leverage resource-based industries had purportedly not been implemented because the industry was considered mature. However, this disregarded the potential for diversification out of the innovative strengths in resource-based industries, successfully undertaken in other countries such as Australia … With respect to the second mission—technology and innovation for poverty reduction—the content of the proposed programme and implementation mechanisms were never clearly specified.

The first of these interventions (resource-based industries) would count as a widow strategy in our framework: there is at least a passing reference to it in the NRDS but, according to the OECD Review, was never implemented. The other even more striking example of a disjuncture between Levels 1 and 2 is the example of the **Pebble Bed Modular Reactor** (which we would classify as an 'orphan' intervention). The OECD Review singled out the PBMR which was neither one of the four missions nor one of the six established or planned centres of excellence in the NRDS. Kaplan writes in agreement (ibid: 11):

As the OECD report stated, the major scale of PBMR has meant that its impact is being felt across the innovation system given its demands for scientific and human resources … PBMR is by a significant margin the largest project employing skilled engineering and scientific labour, said to exceed 600 most of whom are very highly skilled, thus contributing significantly to the shortage of skills. According to OECD, "… it is a significant contributor to the growing demand-supply gap for design and engineering capabilities – probably helping to restrict the ability to achieve important investment-related objectives in other areas of the economy. It is also impinging on R&D at other points in the innovation system. For example, the CSIR has recently lost more than twenty Engineers and Scientists to the PBMR programme, presumably making it more difficult to achieve other important priorities such as its contributions to major DST missions …" (OECD, 2007: 136).

Returning to the first two examples, it must be pointed out that the reality turned out to be even more complicated than indicated in Kaplan's 2008 paper. Kaplan writes the following (ibid: 11):

The OECD findings were that two of these new missions had not been implemented, namely technology related to resource-based industries and technology and innovation for poverty reduction. The lack of implementation in respect to technology and innovation for poverty reduction is particularly problematic with the high levels and persistence of poverty in South Africa despite moderate economic growth. NRDS regarded this mission as particularly critical in the areas of health and education and envisaged projects such as development of affordable household energy systems.

We concur with Kaplan in that there was evidently poor articulation between the references to these two technology missions in the NRDS and what happened afterwards. However, in our review we found that both of these missions were in fact funded and subsequently implemented. The way in which the mission around *resource-based industries* would eventually develop is discussed in detail in David Walwyn's review of this and related strategies (Volume 5: Annexure 14), which is summarised in Volume 3 (Chapter 4). Walwyn shows that although no specific strategy was developed for resource-based industries, it appears that its objectives were incorporated into three other strategies (around advanced metals, mining and minerals and chemical industries):

The NRDS defined two separate technology missions of technology and innovation for advanced manufacturing (TAM) and technology/knowledge to leverage resource-based industries (RBI). Each mission followed separate but also overlapping pathways of implementation. For instance, much of the TAM intent can be found in the planning documents of the Advanced Manufacturing Technology Strategy (AMTS), which later evolved to a specific project area within the Technology Innovation Agency and also became the core focus of the Advanced Manufacturing Technology Directorate within the DST. Henceforth, in this document, activities relating to TAM and AMTS are collectively considered under the titles of ***Advanced Manufacturing Technologies.*** *An analogous strategy specific for RBI was never developed; instead, it appears that the RBI objectives were incorporated into three other strategies or strategic focus areas, namely* ***Advanced Metals (****AM), which includes various initiatives in precious metals, light metals, ferrous and base metals, and new metals;* ***Mining and Minerals****, which includes initiatives such as the South African Mining Extraction Research, Development and Innovation Strategy (SAMERDI); and* ***Chemical Industries****, which was mainly directed into the Fluorochemical Expansion Initiative (FEI).*

The second mission – technology and innovation for poverty reduction – was also not developed into a separate

strategy. However, based on an analysis of the expenditures allocated to different DST programmes over the past 15 years, we found that (a) such a programme was indeed initially funded, and (b) then subsequently renamed as 'Innovation for Inclusive Development'. The table over page summarises the budgeted amounts to these 'programmes' between 2009/10 and 2017/18. Over this nine-year period the total amount budgeted to these programmes sums to R 259.4 million.

In conclusion: The aim of this chapter was to point to different levels of continuity (horizontal and vertical) and disjuncture (over time but also at similar points in time). The examples that we have given illustrate the effect of path-dependency in policy formulation, as well as the symbolic value of rhetorical 'memes' such as the notion of a 'national system of innovation' and 'the linear model of thinking in STI'. But it also points – in the extension of our discussion in the previous chapter – to some of the same 'fault lines' in policy and strategy design and implementation. Finally, as we will discuss in Chapter 4, it also shows the lack of policy learning in STI in South Africa over the past decade – a consequence both of inadequate and inappropriate M&E systems, as well as the lack of sufficient institutionalised capabilities for rigorous and systematic policy learning.

Table 2: Budgets for technology for poverty reduction and innovation for inclusive development (2009/10-2017/18) (R'000s)

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
Technology for poverty alleviation	25 588	10 140	18 328	27 546	25 448	25 395			
Innovation for Inclusive Development							40 732	43 082	43 140

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018
Technology for poverty alleviation	25588	10140	18328	27546	25448	25395			
Innovation for Inclusive Development							40732	43082	43140

CHAPTER 3

SYSTEM GOVERNANCE AND POLICY COORDINATION

3.1 Reflections

Four challenges related to system governance have been highlighted in our review of the NRDS and TYIP. For the most part, these are not new issues or challenges as they have been highlighted and discussed in previous system-wide reviews (2007 OECD review, the 2012 Ministerial STIL Review and the 2017 Ministerial STIIL Review), and recommendations have been made in these reviews to address these challenges. These challenges can be summarised as follows:

1. The DST has struggled to come to grips with how to entrench its (assumed) 'responsibility' as its explicit authority to guide, oversee and/or advise other government departments and their entities in respect of science and research, technology and innovation.

2. "While it seems intuitively obvious that [public research institutions] are expected, at least, to contribute to knowledge generation and socio-economic development, the 2017 STIIL panel was unaware of an **overarching policy document or framework that defines the collective contributions expected of PRIs**" (DST, 2017: 119) "The NDP proposes the alignment of policies, universities, and research institutes to address national challenges, while respecting their autonomy and competitiveness. Instruments are needed for such alignment and to promote the involvement of business (for the economic and human capital aspects) and [NGOs] for the social objectives in the NSI structures" (ibid: 11). The lines of accountability between the DST, DHET and other line departments responsible for science councils "are not adequately constituted in legislation. The Strategic Management Model remains an operational tool and cannot be relied upon to provide a strategic framework in this regard" (ibid: 132).

3. "**Bringing the private sector more centrally into the NSI**, and resolving the considerable vertical and horizontal coordination difficulties arising from the current governance and institutional architecture of the NSI" (DST, 2012: 10).

4. "The responsiveness of the NSI with respect to meeting its intrinsic mandate is most critically dependent on **effective and participatory joint policy-making, planning and coordination at the central NSI policy-making platform**. It is essential that this platform is well-defined in its composition, so that a clear-sighted regulatory environment is achieved, keeping in mind the distinctive capabilities and contributions of the various participants. It is certain that the exclusion from the NSI central policy platform of some actors (such as the private sector), or the persistence of insulated silos (e.g. in some government agencies) contributes to the weakness of the current system. Instead, the NSI central policy

matrix should be reflected in clearly articulated and shared purposes, custom-designed organisational structures and dedicated resource flows. Clearly exercised political will is a paramount condition needed to achieve this coordination" (ibid: 13).

As far as the **issue of governance** is concerned, the 2012 Ministerial STIL Review "recommended for the establishment of a high-level statutory body that would fulfil a range of functions including, among others: prioritisation and agenda-setting; oversight of the system; high-level monitoring; ensuring optimal framework conditions and financial resources and making recommendations for future grand challenges, allocations and equipment" (DST, 2012: 18).

With regard to **policy coordination and planning**, three recommendations were formulated in two previous reviews. The 2012 review recommended that the "the NSI needs at least three well-functioning 'core' policy nexuses: (i) post-school education and training (DHET and DST) (ii) business and enterprise development (at least dti, EDD, DPE and DST) (iii) social development and innovation (DST with departments concerned with social and rural development, social security, health and education)" (ibid.: 20). The 2017 Ministerial STIIL review recommended that "formal, structured R&D and innovation planning should be introduced in every government department and entity at national, provincial, and local levels in order to integrate the practice of innovation into the business of government, thereby directing the available investment funding towards research that will be valuable to low and middle-low income households" (DST, 2017: 132). In addition, the same report also recommends that "an overarching policy framework should be developed for PRIs. It needs to describe the purpose, functions, and governance of PRIs relevant to national development in the next three decades and bear in mind the role of all relevant stakeholders, including those in the private sector. The relevant strategic mandates, in respect of research and innovation, of the DST and other line departments need to be carefully considered, taking into account the current capacities of the PRIs and the extent to which their activities can realistically be aligned with the delivery imperatives of those departments" (ibid.: 134).

Most of the recommendations listed above (especially from the 2017 Ministerial STIIL Review) post-date the publication of the NRDS and TYIP. Since our review focused on these two strategic frameworks, our assessment of the challenges to strengthening system governance was confined to those 'interventions' that were specifically referenced in these two documents. Two such interventions were identified: (1) establishing informal and voluntary inter-departmental task teams to increase cooperation across the system; and (2) the development of a new Strategic Management Model (SMM) to provide conceptual clarity on the differential roles of the DST in relation to other government departments.

In our assessment, neither of these 'interventions' achieved what they were set up to do. Our first conclusion was that "the trust placed in voluntary inter-departmental cooperation across the system has not, perhaps predictably, been vindicated. Examples of these are collaboration agreement between DST and DHET, and the DST-initiated Knowledge Economy Forum activities and structures" (Auf der Heyde, Volume 5: Annexure 1 of this report). Auf der Heyde continues:

> *The SMM attempted to create a conceptual basis for differentiating the roles of the DST and other government departments in relation to STI, in order, presumably, to institutionalise these roles in due course through appropriate organisational platforms, interdepartmental agreements, and, possibly, relevant legislation (as illustrated by one of the actions proposed in Cabinet Memorandum No. 19). Presumably, the choice of activities outlined in the memorandum was assumed at the time to suffice for comprehensive implementation of the SMM as the key intervention to shore up system-level governance and coordination. However, our review shows that the SMM constituted an insufficient intervention. Moreover, the activities listed in the cabinet memorandum only addressed some of the key policy imperatives that had been set out in the NRDS – many were not acted on. It therefore seems reasonable to conclude that prevailing political conditions in the 2003-2004 period limited the extent to which the NRDS policy intents could be pursued, and that the content and form of the SMM as it was implemented in late 2004/05 constituted the most viable compromise at the time.*

In his assessment, two key interventions could have achieved better outcomes:

> *Two key interventions would have positioned the DST at the centre of public sector science and technology (and research) activities, though they would not have imbued the DST with central responsibility for innovation: namely the transfer into the DST of all major public research institutions, and the establishment of an Act entrenching the DST's functions across the system as a whole. Both*

these interventions were explicit policy intents at one point or another in the development of Cabinet Memorandum No. 19 (implementing the SMM), but neither was ultimately taken forward. It seems reasonable to assume that this failure is a manifestation of political dynamics prevailing at the highest levels of government at the time.

Auf der Heyde concludes:

… several of the NRDS's less intrusive policy intents – that is, those which undermined less the authority of other line departments over their respective public science institutions – were given effect through the implementation of the SMM as laid out in Cabinet Memorandum No. 19. But the more ambitious policy imperatives which would have secured the DST's role as the formal interlocutor on behalf of most public sector science, technology and research activities and institutions have largely not been implemented over the last decade-and-a-half – despite being mostly codified in the NRDS and Cabinet Memorandum No. 19, and repeated to a lesser extent in the TYIP. This lack of substantive movement in entrenching the leadership role of the DST in respect of public sector STI is presumably why the 2019 White Paper still makes extensive reference to the need for strengthened system-level governance of STI.

3.2 Uptake of these recommendations in the 2019 White Paper

In its discussion of system governance and coordination challenges, as well as system performance review, the 2019 White Paper takes most of the recommendations from the 2017 STIIL review on board. Five specific 'interventions' are highlighted:

1. The establishment of a standing ministerial-level STI structure that will perform functions of (high-level) agenda-setting, approval of decadal plans, resource allocation and performance review.
2. The establishment of an STI plenary as a platform for more inclusive policy and planning engagement across all stakeholders.
3. The establishment of three policy nexuses to improve implementation of STI-related interventions across all government departments.
4. The development of sector STI plans to ensure integrated STI planning across all sectors (expanding beyond manufacturing and agriculture).
5. The development of an integrated policy framework that sets out the governance arrangement and mandates of public research and innovation institutions.

We elaborate on each in the table below.

Table 3: Elaboration of interventions relating to system governance, coordination and performance review in the 2019 White Paper

Action	Elaboration
Establish a standing ministerial-level STI structure (chaired by Minister of HEST) with the aim of (centralised) agenda-setting, approving decadal plans, resource allocations and performance reviews.	A standing ministerial-level STI Structure, chaired by the Minister of Science and Technology, will be established. The Ministerial STI Structure will comprise the relevant STI-intensive departments, the chairpersons of the government clusters, National Treasury and the DPME. The committee will focus on setting a high-level public **agenda** for the NSI, approving **decadal plans on innovation** for South Africa, committing **public resources** to research and innovation, and r**eviewing reports on the performance** of the NSI over three-year cycles. To advise the Ministerial STI Structure, a strengthened NACI will undertake such studies, and will also function as an M&E institution for the NSI. As part of this expanded mandate, NACI will work with the DST to develop an annual high-level STI investment framework to support the commitment of public resources for STI by the Ministerial STI Structure. It will also do regular environmental scanning to support the agenda-setting function of the Ministerial STI Structure. To help expand its capacity, NACI will work with other sources of technical expertise and data in the NSI, such as the Centres of Excellence and Research Chairs.

Action	Elaboration
Establish a STI Plenary for engaging all stakeholders in collaborative planning, performance assessment and resource allocation	To ensure that STI enjoys the required support and stature across government and society, an annual STI Plenary will be convened by the Presidency. The STI Plenary will include business, government, academia and civil society. The STI Plenary will serve as a collaborative platform. The NSI partners will use the STI Plenary to collaboratively reflect on progress with STI initiatives, strategise to address challenges, make recommendations on actions required, and jointly commit resources for the recommended initiatives.
Establish three policy nexuses for improved coordination of implementation plans across government	A number of well-functioning "core" policy nexuses will be established to harmonise and coordinate implementation plans – while taking account of the functions and roles of relevant government clusters. These policy nexuses include the following: • **Education and skills development:** This nexus will focus on education and training involving the DHET, the DST, the Department of Social Development, the DBE and the Department of Labour. • **Economy:** This nexus will focus on business and enterprise development, involving at least the DST and the departments of Trade and Industry, Economic Development, and Public Enterprises. • **Social:** The focus of this nexus will be on social development and innovation for inclusive development, involving the DST and departments concerned with social and rural development, and the social security-health-education nexus.
Initiate integrated STI planning for priority sectors (sector STI plans to be managed by a DSI coordinating committee)	Integrated STI planning for priority sectors will be adopted, resulting in the development of sector STI plans. These will be used to coordinate the research effort across industry, science councils and universities, and to concentrate funding on priority initiatives. The development and implementation of the sector STI plans will be driven by a committee involving all stakeholders, specifically business and industry associations. The DST, in collaboration with the relevant line department, will manage this committee. The sector STI plans will be supported by financial and non-financial instruments. Sector Innovation Funds, which have been introduced mainly in the agriculture and mining sectors, will be enhanced and expanded to include other priority sectors. Government instruments that are aimed at coordination, such as inter-ministerial committees, the cluster system and memorandums of agreement, will also be employed where appropriate to ensure coherent action across sectors to implement the sector STI plans.
Develop an overarching policy framework for PRIs	An overarching policy framework be developed that sets out the purpose and governance of public research (and innovation) institutions. The policy framework will further define the role of government departments with respect to the sector-specific science councils that report to them. Consequently, under the guidance of the DST, such a policy framework will be developed to describe the purpose, functions and governance of PRIs relevant to national development as guided by the NDP, taking into account the roles of all stakeholders. This will involve clarifying the general purpose of such institutions and the strategic mandates of the DST and other line departments in this respect, and taking into consideration the current capacities of these institutions. Interventions to enhance coordination across different PRIs and funding agencies will also be developed. The work of the STIIL Review Panel will inform the implementation of the policy framework by way of the decadal plan.

3.3 Conclusions and recommendations

The following conclusions can be drawn from the discussion thus far:

- There is a strong consensus across all the different reviews – now spanning nearly 20 years – about the key challenges in the STI system around governance and institutional differentiation and coordination. The fact is that nearly every review identifies the same problems – lack of an integrated policy framework; lack of vertical and horizontal coordination across departments and public research agencies; lack of a singular science vote; lack of central and independent science advisory bodies; and inadequate evidence on the system that would allow for better monitoring, evaluation and planning (including foresight). It is also worth noting that the 2019 White Paper agrees with much of this assessment.
- Where there has been progress in some instances (as with the SMM), these are deemed to have only had limited effect. In other cases, some recommendations have been taken up (such as the institutionalisation of M&E in the system as advocated in the 2019 White Paper).
- But the fact that so many (similar) recommendations have been made that have not been enacted upon, suggests deeper and recalcitrant obstacles to uptake. It seems as if the new White Paper has 'given up' on going the route of legislation, and instead reverted to other instruments: using funding (sector funding) to enforce coordination across departments; softer mechanisms (such as MoAs, a new policy framework and setting up committees); and then use M&E as a tool to ensure compliance with such new measures. Using M&E as a tool to manage and enforce change rather than as tool for learning is a dangerous strategy. It often simply leads to empty compliance or some form of gaming the system!

This leads us to the following recommendations:

Recommendation:
We strongly re-affirm the findings of previous reviews regarding the necessity of a strong, central STI governance body such as the proposed ministerial-level STI structure

Previous attempts at achieving a similar structure have come to nought which suggests that STI issues do not seem to have the same high-level traction when compared to other national priorities. Ironically, the current experience around the state's response to the Covid-19 crisis may support future attempts to establish such a central structure. It is clear, not only in South Africa, that the pandemic has re-legitimised the value of and trust in science, facts and evidence. The re-affirmation of the necessity of a strong science base in a country to deal with societal challenges may well be a sufficient trigger to galvanise Cabinet to approve the establishment of such a ministerial-level structure.

Recommendation:
We re-affirm previous recommendations regarding the necessity of policy coordination, and hence support the proposed establishment of a national STI plenary

Although we support this recommendation – as phrased in the new White Paper – we would also recommend that some essential preparatory investigation is done on the mandate of such a plenary and how it will function most effectively. If such a plenary is in fact tasked with addressing the challenge of policy coordination across sectors and government departments, it will have to be given the required authority to do so. If not, it will simply become yet another informal forum for the exchange of ideas of which the system already has many examples.

Recommendation:

With regard to the establishment of three policy nexuses to improve implementation of STI-related interventions across all government departments, we suggest that this proposal be subjected to further scrutiny and investigation

The proposal to establish three policy nexuses has its origins in the 2012 Ministerial Review of the Science, Technology and Innovation Landscape and is included in the 2019 White Paper. According to this proposal, three nexuses would be established to harmonise and coordinate implementation plans in education and skills development, the economy, and the "social" (sic). It is not clear how these specific nexuses were arrived at, but we believe that the uncritical implementation of this proposal might in fact be counterproductive as it could end up creating more silos in implementation and less coordination across sectors and government departments. How, for example, will cross-cutting issues between education, the economy and society be addressed under this model? And, how will the establishment of these nexuses align with initiatives to expand and deepen the framework of societal challenges?

CHAPTER 4

MONITORING, EVALUATION AND LEARNING

4.1 Reflections

Our review of the NRDS and TYIP and the associated subsidiary strategies and interventions discovered many shortcomings at all levels of the NSI in terms of M&E expertise. Although there is some evidence of improvement over time, it is clear that M&E capabilities in terms of outcome-mapping and target-setting, indicator construction, performance measurement, use of appropriate data sources and impact evaluation remains below par. However, in fairness our assessment of the state of M&E in the domain of STI needs to be interpreted against the background of the progressive institutionalisation of M&E in South Africa since 1994.

4.1.1 Overview of performance measurement in South Africa[108]

Following the abolishment of apartheid in 1994, the new ANC-led government undertook a major overhaul of the public sector as "prior to 1994 much of the population was excluded from service delivery, services to citizens were fragmented by ethnicity and there was no integrated system for data or measuring performance" (CLEAR, 2012: 145).[109] According to Cameron and Tapscott (2000: 81)[110] the reform agenda needed to enhance accountability, while addressing the needs of the citizens: the "authoritarian, repressive and oligarchic" state had to be replaced with one that is "democratic, developmental and committed to a culture of human rights." The newly-elected government developed the *White Paper on the Transformation of the Public Sector* in 1995, which listed a number of imperatives for the new public service. One of these is especially relevant to our discussion, as summarised by Miller (2005):[111] "Ensuring *professionalism and accountability* was enacted through the establishment of various government bodies such as the Public Protector, Auditor General and Public Sector Commission. It was also prescribed that Director Generals will be held accountable via performance measures. Professionalism was advanced through the introduction of a code of conduct for the Public service."

Miller (ibid: 70) states that much of the reforms in South Africa paralleled those which were implemented in other countries, in particular Britain and the US. The Director-General for Public Services and Administration, Richard Levin, as cited in Cameron (2009),[112] argues that public sector reform in South Africa has been shaped by the tenets of new public management, including a strong focus on decentralised management of human resources and finance.

[108] This section is extracted from Charline Mouton's doctoral thesis manuscript (2020) entitled "Performance measurement of policy priorities: Development of a measurement approach to enhance the tracking of government performance".

[109] CLEAR. 2012. African Monitoring and Evaluation Systems: Exploratory case studies. A collection of case studies facilitated by the CLEAR Initiative-WITS. Johannesburg: Graduate School of Public and Development Management, University of the Witwatersrand.

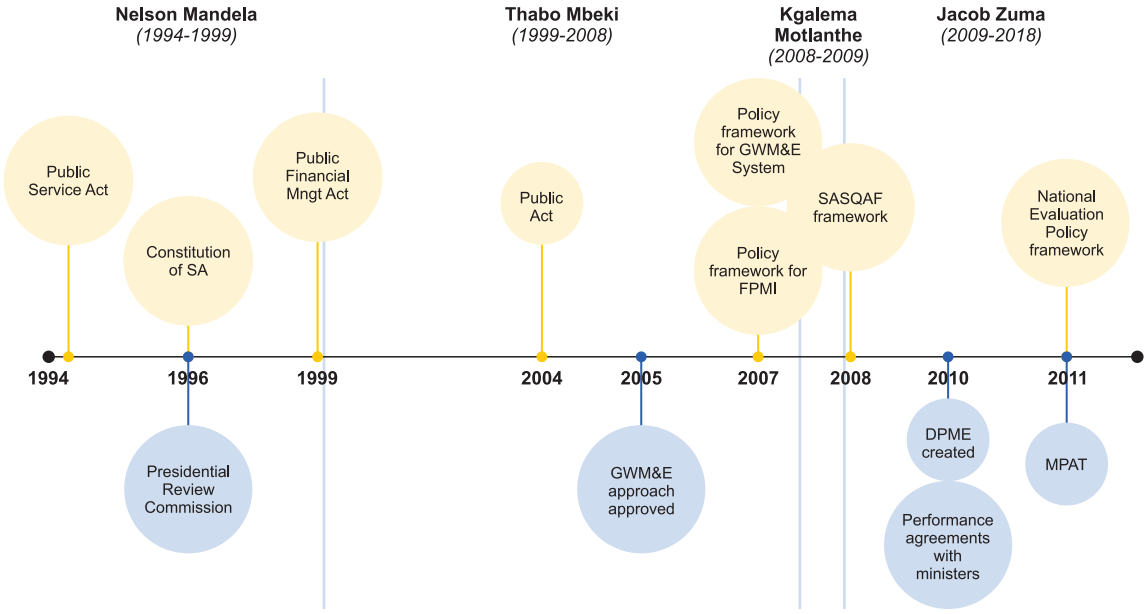
[110] Cameron R & Tapscott C. 2000. The challenges of state transformation in South Africa. Public Administration and Development, 20(2):81-86.

[111] Miller K. 2005. Public Sector Reform: Governance in South Africa. England: Ashgate Publishing.

[112] Cameron R. 2009. New public management reforms in the South African public service: 1999-2009. Journal of Public Administration, 44(4.1):910-942.

Figure 13 provides a historic timeline of the key initiatives/events and policies enacted to institute performance measurement in the South African public sector. It is by no means a comprehensive account of all the events and policy documents drafted in support of a more efficient, effective and accountable government. Yet, its purpose is to provide the reader with a 'headline' view of how performance measurement evolved in the South African public sector post-apartheid. For the time period under review, four different presidents have headed the country since 1994: Nelson Mandela, Thabo Mbeki, Kgalema Motlanthe and Jacob Zuma.

Figure 13: Major performance measurement policies, legislation and initiatives under the different presidents



Key: Yellow = policies and legislation, Blue = initiatives/ key events

A brief description of the performance measurement-related aspects of the policies and legislation included in the figure above are set out in the table below.

Table 4: Performance measurement-related policies and legislation

Policies and legislation related to performance management	Purpose of policies/legislation
1994 Public Service Act and Regulations	The Public Service Act (1994) saw the establishment of three spheres of governance. The Act also addresses staff appointments and managing staff performance. The 1999 set of regulations introduces performance agreements for senior officials and sets a framework for managing performance of Heads of Departments
1996 Constitution of South Africa	Sections 92, 133 and 195 of the Constitution addresses issues around government performance by way of the 3Es (Efficient, Economic and Effective use of resources), encouraging greater transparency by making information available to the public and putting structures and stipulations in place surrounding lines of accountability
1999 Public Finance Management Act (PMFA)	Regulates financial management in national and provincial government. This included non –financial performance with Accounting officers needing to report against predetermined objectives. Paved the way for the development of Strategic plans and Annual Performance Plans (Started in 2000 for provinces and 2010 for national). Also ensured a shift from inputs to outputs

Policies and legislation related to performance management	Purpose of policies/legislation
2004 Public Audit Act, Act 25 of 2004	Legislates the auditing of performance information for all three spheres of government. The Auditor General is the responsible body. An annual audit report is produced that assesses the quality of performance information, the accompanying evidence as well as the quality of the performance information systems
2005 Government-wide Monitoring & Evaluation (GWM&E) framework	Government approves a plan to implement a "system of systems" that prioritised a functional monitoring system, bearing in mind the existing M&E capacities
2007 Government-wide Monitoring & Evaluation Policy Framework	This policy document expanded on the development of the systems included in the GWM&E: Frameworks for Programme Performance Information (FMPPI), Quality of statistical data and Evaluations. Following from this policy documents were produced for the three sub systems: National Treasury: Framework for Managing Performance information (2007) Statistics SA: South African Statistical Quality Assessment Framework (2008) The Presidency: National Evaluation Policy Framework (2011)

The government-wide M&E system encapsulates all aspects of performance measurement within the South African context and gives effect to the need for an integrated performance approach as identified by the Presidential Review Committee in 1996. Cloete (2009: 298)[113] identified the following push factors for the development of a government-wide monitoring and evaluation system:

- A need to report back on the UN Millennium Development Goals;
- A lack of a national M&E system even when South Africa was hosting the World Summit on Sustainable Development in 2002;
- No platform to provide feedback to citizens about government's Programme of Action;
- Increased pressure from donors for more systematic assessment of programmes; and
- The importance attached to M&E systems worldwide in enhancing governance.

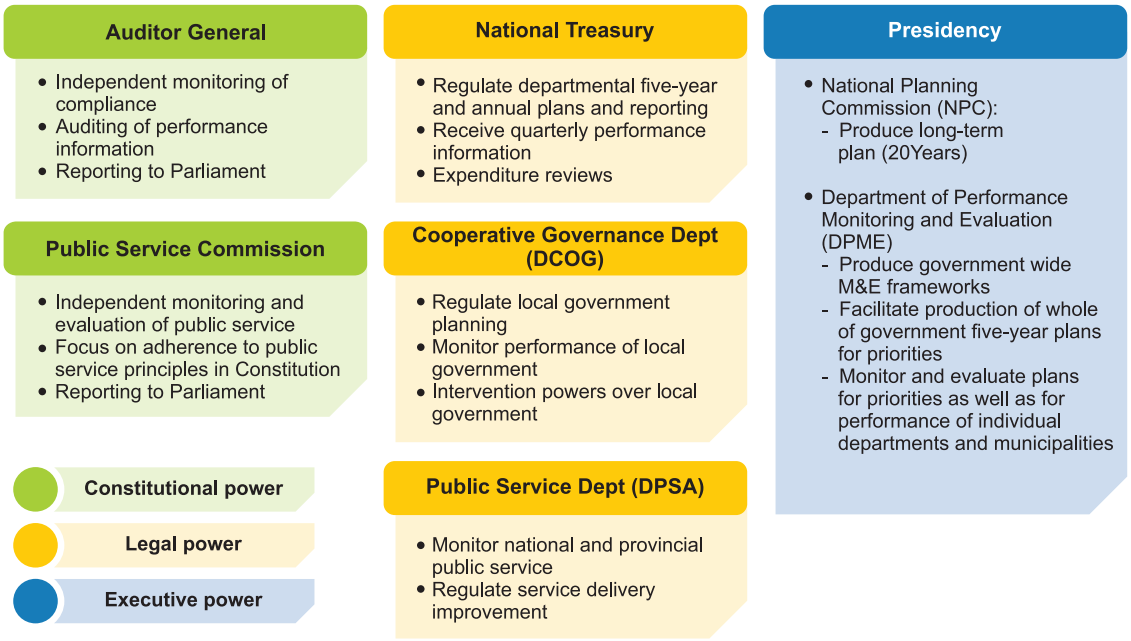
With Cabinet granting approval to proceed with the development of a Government Wide Monitoring and Evaluation (GWM&E) system in 2005, work commenced on drafting a policy framework for the GWM&E system. This policy was released in 2007 describing the inter-relatedness of the three sub data terrains of programme performance information, statistical data and evaluation. Following from this, three separate policy documents were developed setting out the detail of each data terrain:[114]

- Framework for Managing Performance Information (FMPI) (2007): This document describes the alignment of performance information from all three spheres of government with the GWM&E system, the role of performance information in planning, budgeting and reporting, guidelines in constructing performance indicators and clarification of key concepts.
- SA Statistical Quality Assurance Framework (SASQAF) (2008): The first edition of this framework provides the dimensions against which data quality and statistical products are assessed.
- National Evaluation Policy framework (2011): The Policy Framework sets out to institute a minimum system of evaluation across government with the aim of promoting quality evaluation and ensuring results are used to improve government performance. It also clarifies evaluation related terminology.

[113] Cloete F. 2009. Evidence based policy analysis in South Africa: Critical assessment of the emerging government-wide monitoring and evaluation system. *Journal of Public Administration*, 44(2): 293-311.
[114] DPME. 2011. National Evaluation Policy framework. The Presidency, Republic of South Africa; Mouton C. 2010. The History of Programme Evaluation in South Africa. MPhil thesis, University of Stellenbosch.

The need to bring about greater coherence between the three agencies in charge of these sub-systems (i.e. The Presidency, National Treasury and the National Statistics Agency) was also highlighted in the 2007 policy document. Figure 14 distinguishes between these various M&E stakeholders on the basis of their constitutional, legal and executive power.

Figure 14: M&E stakeholders in South Africa[115]



A pivotal event in the South African history of performance measurement was the establishment of the DPME in January 2010. In 2011, inspired by the Canadian approach to assessing management performance, the DPME introduced the Management Performance Assessment Tool (MPAT). The need for this tool came as a result of the gap for management performance information, as opposed to service delivery information (Phillips et al., 2014).[116] The MPAT is one of several initiatives to improve the performance and service delivery of national and provincial departments. MPAT is a structured, evidence-based approach to the assessment of management practices. The tool was jointly developed with National Treasury, DPSA, and Office of the Public Service Commission, Office of the Auditor General and Offices of the Premiers. It considers performance of national and provincial departments against 31 management standards covering 17 management areas.

It is evident from the various initiatives and legislation that great strides have been made in creating a more formalised performance measurement culture in South Africa, mainly under the auspices of the GWM&E system. These efforts continue, notably by establishing a culture of evaluation to give effect to the National Evaluation Policy Framework. Mechanisms in support of this endeavour include the establishment of an Evaluation and Research Unit in the DPME, a cross-government Evaluation Technical Working Group, the drafting of Evaluation standards and guidelines, as well as continuous capacity-building efforts around evaluation and setting annual evaluation study targets.

4.1.2 Main shortcomings in M&E

At the time that the NRDS was published in 2002, there was as yet no formal structure in place in the public sector that would guide the design of policies and strategies regarding performance measurement or monitoring. As our timeline above shows, it would only be in 2005 when the Government-wide Monitoring and Evaluation Framework was adopted, and that guidelines were published to assist government departments and public sector agencies in a more systematic manner with M&E. But it should also be remembered that Annual Performance Plans (which include statements of outputs, targets and indicators) were required as of 2000.

[115] Source: Goldman I, Engela R, Akhalwaya I, Gasa N, Leon B, Mohamed H & Phillips S. 2012. *Establishing a national M&E system in South Africa.* The World Bank Special Series on the Nuts & Bolts of M&E Systems, September, no. 21.

[116] Phillips S, Goldman I, Gasa N, Akhalwaya I & Leon B. 2014. A focus on M&E of results: An example from the Presidency, South Africa. Journal of Development Effectiveness, 6(4): 392-406.

By the time that the TYIP was published in 2008, things had changed fundamentally. M&E imperatives and requirements were much more entrenched in the public sector, and a very 'pervasive' and standardised form of reporting on M&E had become the norm. In the recent past the nature and scope of M&E demands have become even more comprehensive. Significantly, with the publication of the National Evaluation Policy Framework in 2011, a major shift occurred. Whereas the pre-2011 era can be described as being predominantly focused on performance monitoring and compliance reporting, the emphasis now is on reporting on outcomes and impacts (in the terminology of the Work Bank – on results). As a corollary to this, government departments are now also required to regularly conduct (external) impact evaluations of their major interventions.

In a recent report submitted to NACI,[117] SciSTIP identified more than 100 evaluation studies and reviews that pertain to the NSI that have been undertaken since 1998. Our assessment of the policy intents in the NRDS and TYIP identified three problem areas:

1. There has been insufficient coordination within the STI system in the commissioning and execution of evaluation and review studies; with the result that …
2. there has not been any systematic learning and uptake of these results to inform STI policy, strategy and planning; which in turn can be attributed to …
3. a general lack of capacity and technical expertise in policy and strategy design and analysis.

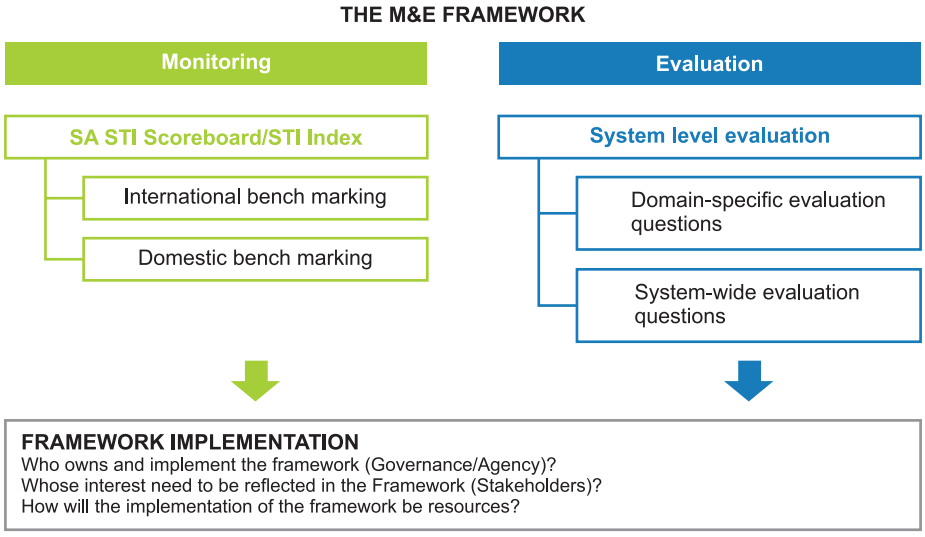
This leads us to the following recommendations.

4.2 Recommendations

Recommendation:
Implement a system-wide monitoring and evaluation framework for the STI system

An explicit monitoring, evaluation and learning framework needs to be implemented for STI in South Africa. In a recent report to NACI, SciSTIP presented the broad outlines of such a framework. Our first recommendation is that this framework is adopted and implemented as a system-wide M&E framework for the STI system.

Figure 15: M&E Framework for the South African STI system



The proposed framework makes a clear distinction between 'monitoring' objectives and 'evaluation' goals. The M-part presents the criteria for systems-level performance indicators and a variety of possible candidates – ranging from background 'context' indicators to high-priority 'key performance' indicators. We took our cue from the 'European Innovation Scoreboard' as an appropriate indicator-based model for designing such an analytical tool in South Africa. Such a tool should distinguish between two important but complementary functional approaches to assess the general health of the STI system: international and domestic benchmarking.

[117] SciSTIP. 2019. *Report on a Monitoring and Evaluation Framework for the South African Science, Technology and Innovation System*. Stellenbosch.

The E-part of the M&E framework follows a theory-based evaluation approach and focuses on systems-level evaluation questions related to prior or ongoing STI policies and (proposed) interventions. STI policy intents and ambitions in the 2019 White Paper provide one input for the structuring. Other relevant questions relate to systems-level issues in South African STI domains, but may also derive from international and global trends in STI. An M&E framework for the STI system requires a tailor-made approach with a strong emphasis on the connectivity between actors and processes within the system – both national and international. Adopting a 'national system of innovation' model is not sufficient to accommodate these requirements. We thus distinguish between domain-specific evaluation questions (D-**Eqs**) and system-wide evaluation questions (S-**Eqs**).

Recommendation:
Establish a national data centre (or 'observatory') on the South African STI system

Various initiatives have been attempted over the past decade to establish a national (virtual) centre that would combine and integrate all relevant data on key components of the STI system. These initiatives have thus far come to nought. Data continue to be housed at different institutions: on research funding and expenditure (CeSTII and various government departments); human resources for S&T (DHET and its Higher Education Management Information System); scientific publications (CREST); agency funding (the NRF, MRC, WRC, Agricultural Research Council and others); and IP indicators (NIPMO). Various countries have established national observatories for STI, or at least national centres where such data is housed centrally and made available for analysis and research. Typically, such observatories are not housed within government departments or agencies, but either established as independent agencies (e.g. OST in France) or linked to one or more universities (e.g. the Centre for R&D Monitoring at the University of Leuven in Belgium). We recommend that serious consideration be given to the establishment of such a data centre or observatory, especially if the recommendation above regarding the implementation of a system-wide M&E framework is accepted. The implementation of a system-wide M&E framework will require that an integrated science and innovation data facility is established.

Recommendation:
Institutionalise (continuous) professional development in research evaluation

There are currently initiatives afoot in the M&E sector in South Africa to strengthen and institutionalise a standard set of M&E competencies for all professionals who work in this area. This initiative, which is driven by the South African Monitoring and Evaluation Association, aims to develop a certificated course to ensure that all M&E professionals in the public sector adhere to international best practice in this field. Our specific recommendation is that this initiative be adopted within the STI system, but also adapted to the specific requirements of monitoring and evaluating the ongoing performance and achievements of STI interventions and programmes. Adopting this approach means that general principles that apply to M&E need to be customised for the specific demands of STI policy reviews and assessment, research programme and institutional evaluations, technology assessment and other STI-specific interventions.

Recommendation:
Establish a mechanism to ensure policy learning across the system

Our review has highlighted the fact that STI policy learning has been sub-optimal. The analysis of the NRDS and TYIP revealed examples of (1) repetition of similar findings over time, (2) repetition of recommendations from review to review, and (3) general lack of 'monitoring of uptake and learning'. It is recommended that policy learning is institutionalised in the system with the mandate to conduct regular meta-reviews of all higher education and STI reviews, and to organise policy learning forums with relevant stakeholders in order to ensure more consistent and appropriate uptake and use of system and programme reviews.[118]

[118] SciSTIP is currently developing a concept paper for the establishment of a Higher Education and STI Policy Lab. Such a Lab would (a) conduct and publish systematic reviews of international good practice in policy learning and policy experimentation; (b) develop workshops around policy experimentation and uptake; and (c) conduct case studies of policy learning.

CHAPTER 5

HUMAN RESOURCES FOR SCIENCE AND TECHNOLOGY

5.1 Reflections on the current state of human resources for S&T

The recent report by CREST, *The State of the South African Research Enterprise*,[119] identified the area of human resources for S&T (together with the need to increase investment in research and innovation) as arguably one of the main challenges for the South African S&T system. In our summary on the existing human resources capacity we concluded as follows:

The research capacity in the country is too small and needs to be expanded as a matter of urgency. This point is vividly made by the fact that our comparator countries have on average twice as many full-time equivalent researchers per thousand of the workforce and three times as many per million of the countries' inhabitants. Our low spend on R&D are also reflected in South Africa's low ranks on these two research capacity indicators in 2015: 62 and 69, respectively. Even though we have made great strides in expanding the doctoral pipeline over the past 15 years, the ratio of doctoral graduates to millions of the population remains well below international average.

A first inspection of R&D statistics on the **researcher capacity** of the country would suggest a positive picture. South Africa's number of researchers increased – both by headcount and full-time equivalents (FTEs are used to add up the contribution of people who work part time). Total researcher headcount increased from 45 935 in 2013-14 and 48 479 in 2014-15 to 51 877 in 2015-16. That is a dramatic jump of almost 3 400 researchers. However, it is important to understand that most of this increase is due to an increase in the numbers of postgraduate students and post-doctoral researchers. Conversely, that jump masks a decline in full-time equivalents employed as researchers within universities. Within universities, FTE researchers, not including postgraduates, declined from 5 097.7 in 2014-15 to 4 701.9 in 2015-16. This is the first time FTE researchers has declined in the last decade.

Against this background it is not surprising that the **international benchmarking of South Africa's research capacity makes for depressing reading**. On all the key indicators, South Africa occupied a position between 62 and 69 in the world in 2015. The Comparator countries have, on average, twice as many researchers per thousands of the population (FTE) and three times the number of researchers per million of inhabitants than South Africa. In fact, on these latter two indicators South Africa's profile is much more similar to the average country in Africa.

[119] Mouton J, Basson I, Blanckenberg J, Boshoff N, Prozesky N, Redelinghuys H, Treptow R, Van Lill M & Van Niekerk M. 2019. The State of the South African Research Enterprise. Stellenbosch: SciSTIP.

The comparison with the Lead countries is even more indicative of the dire position of the country: the average Lead country has 15 times more researchers per million of the population than South Africa.

The more positive picture that emerges around **doctoral production** requires further elaboration. Actual number of doctoral graduates increased from 972 in 2000 to reach 2 794 in 2016 and to 3 350 in 2018. This has meant that the average number of doctorates per million of the population increased commensurately from 21 in 2000 to 49 in 2015. It is most likely that this increase was driven both by national strategies and interventions (such as the PhD as Driver-strategy of the NRF), as well as the changes in the DHET funding framework for research at SA universities. As to the latter, the framework was changed in 2005 to include research masters and doctoral students in the subsidy framework. Universities now receive significant amounts of subsidy for the production of research graduates. It is clear from the increase in the numbers since 2008/9 that the incentive scheme has been extremely effective.

However, when compared with other countries in the world, **the improvement in the ratio of doctoral students to millions of the population (46 in 2015) does not compare favourably with the lead countries (or even the majority of the comparator countries**). The lead countries such as Slovenia, Switzerland and the UK had more than 400 PhDs per million of the population in 2015. Most of the Scandinavian countries and Austria had more than 300 PhDs per million of the population. The top comparator countries – Portugal (227), Greece (148) and Malaysia (132) – recorded three to four higher ratios than South Africa. And even when compared to other African countries, South Africa lags third behind Tunisia (118) and Egypt (73). **It is clear that despite the substantial increase in doctoral production, South Africa still has a long way to achieve some level of parity with the top countries in the world (and on the African continent)**.

There are two key imperatives with regard to human capital development in the NSI: to grow and expand the human resources base for S&T, and to transform the human resource base to become more inclusive of (South African) black and women academics and scientists. Although these two imperatives are not necessarily mutually exclusive, specific strategies to achieve the goals of growth and transformation can produce tensions and, in fact, counteract one another.

The challenges related to expanding and transforming the human resource base for S&T are not new. These challenges were recognised in the 1996 White Paper and are re-iterated in the 2019 White Paper. They are also mentioned in some detail in the NRDS (the reference to the 'frozen demographics') and TYIP. Our reviews of the NRDS and TYIP have shown that these strategic frameworks and subsidiary strategies (e.g. the CoE and SARChI programmes, various science awareness strategies such as the Youth into Science Strategy, as well as references to increasing the international flow of highly skilled people to South Africa through increased collaboration with African countries) are based on three common strategies to achieve the end-goal of increasing the human capital base:

1. To attract local talent to science (especially the SET fields) through science awareness interventions;
2. To retain local talent through the reduction of attrition and drop-out over the course of the academic pipeline (from undergraduate to doctoral degrees) as well as subsequent (early careers) of academics and scientists; and
3. To attract foreign talent through various internationalisation strategies.

5.2 The imperative to attract and retain local talent for the science system

It is important to emphasise that the first two strategies – to attract and retain local talent – need to be addressed together. Unless those (learners, students) who enter the post-school system and the science system are retained in the system, the strategy remains an incomplete response to the challenge. Hence this strategy's 'theory of change' should ready as follows:

1. **If** we increase the pool of learners (in the schools) who enter the post-secondary school system (universities and TVET colleges) **and**
2. **If** university (and college) entrants are retained in the system and complete their studies successfully **and**
3. **IF** our graduates enter into the South African labour market **then** we should have a sufficient (and growing) pool of future academics and scientists for the national system of innovation.

We will refer to the formulation above as the *general theory of change for expanding the human resource base*. However, in many of the national policy and strategy documents (including the NRDS and TYIP), specific strategies are highlighted to attract and retain learners and students to the **science, engineering and technology (SET) fields**. In fact, the NRDS (Chapter 4.4) nearly exclusively refers to the development of SET human capital development. This explains why more indicators related to human resources for the SET fields are listed in the NRDS than general human resources-related indicators. We will refer to this as the *special SET theory of change for expanding the human resource base*.

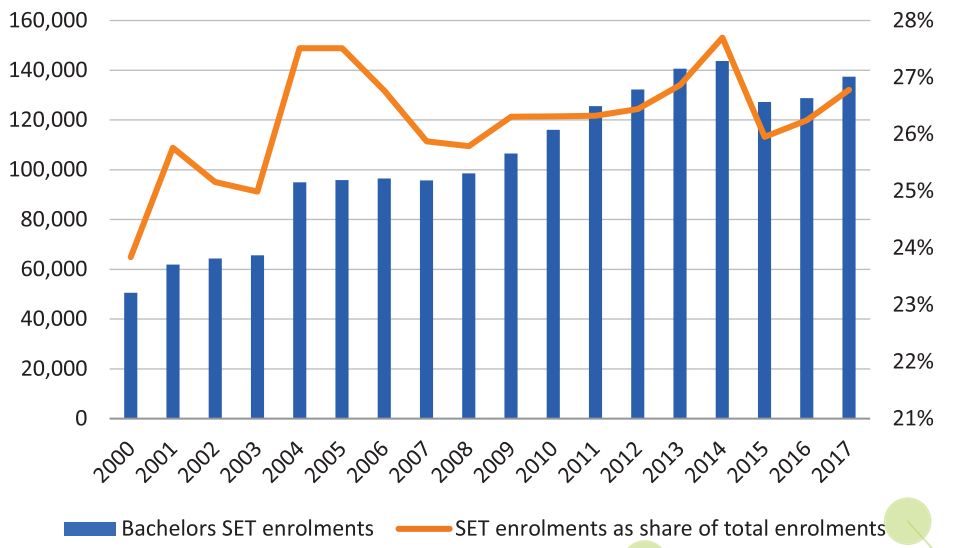
With regard to attracting local talent to science, it is not surprising then that the DST, DHET, NRF, ASSAf, the NSTF and various other bodies (including SAASTA)[120] have all invested significant resources and effort into raising awareness among high school learners of the importance and value of science and careers in science. Both the 2006 Youth into Science Strategy and the much later 2016 Science Engagement Strategy include references to a multitude of interventions to achieve this goal. These interventions range from organising science festivals, science weeks and visits to science centres and museums, to distributing magazines such as Quest to thousands of schools, and recognition of top performance in mathematics and science through various awards and prizes.

What is also noteworthy is that the responsibility for creating greater awareness of science among high school learners (and the general public) is no longer confined to specific agencies such as SAASTA, but is now included as part of the key performance areas of the flagship programmes of the NRF – the Centres of Excellence and SARChI. In both cases, recipients of grants under these programmes are also expected to devote significant effort to programmes in science education, science promotion and science engagement. This expanded focus is also reflected in the establishment of the first two SARChI Chairs in science communication at Stellenbosch and Rhodes in recent years.

Despite the increase in science awareness and science engagement interventions, the reality is that the pool of potential SET students for the higher education system has not grown substantially over the past two decades. As shown in our discussion in Volume 3 (Chapter 3), the proportion of school learners who pass Mathematics in Grade 12 (with a grade at 60% or higher) has in fact declined from around 9% in 2010 to 7% in 2018, while the percentage of Grade 12 learners with a pass rate of 60%+ in Physical Science constituted only 7.6% of all matriculants in the same year.

Two other sets of information, as presented in Figure 16 below, give very little hope that this problem will be solved in the near future. The first is the annual enrolments in SET fields at the bachelors level (blue bars); the second is the proportional share that these enrolments constitute of total bachelors enrolments in SET fields. The results show that the actual numbers of enrolled students in SET fields increased from 50 588 in 2000 to 137 371 in 2017. The line graph shows that the proportional shares of SET students have, however, only increased marginally from 24% to 27% over this period. The national target of SET enrolments reaching 35% by 2018, as stated in the TYIP, is clearly not achievable.

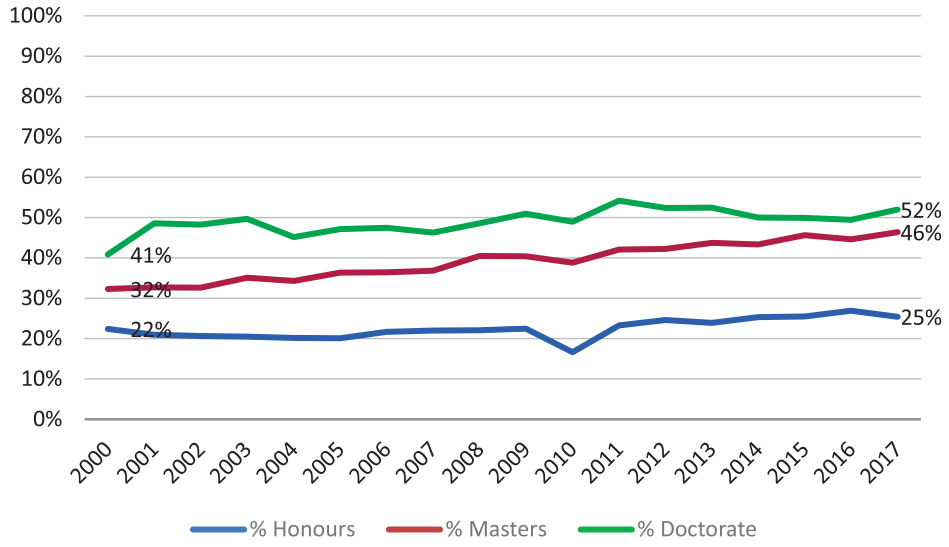
Figure 16: Bachelors SET enrolments and share of SET enrolments of total enrolments (2000–2017)



[120] South African Agency for Science and Technology Advancement.

The only 'consolation' is that the proportions of SET enrolments and graduates at the masters and doctoral levels (but not at honours level) are higher and have increased steadily over time. The graph below shows the trends over time for postgraduates at each level.

Figure 17: Postgraduate enrolments in SET fields (2000-2017)



It is evident from numerous policy and strategic reviews over the past two decades that the root cause of this problem remains the poor performance of the schooling system in producing sufficient numbers of high quality matriculants in Science and Mathematics. This was already recognised by the 2007 OECD Review. The 2012 Ministerial STIL review referred to this problem as the key weakness of the NSI: "The NSI depends almost entirely on the effectiveness of the basic education and post-school systems. The NSI cannot work well if the available human capital is not adequate or equal to the task" (DST, 2012: 30). The issue is reiterated in the 2017 Ministerial STIIL report (DST, 2017: 20): "The human resource development requirements of a knowledge economy are critical for a functional NSI and the dysfunctionality on all levels of the higher level education system is of grave concern."

The second part of the challenge to **retain** local talent in the system remains an equally difficult goal. In 2013, the DST commissioned CREST to undertake a comprehensive study on the retention, completion and progress rates of South African postgraduate students. The final report on this study appeared in early 2015. The report provided the first detailed evidence of some of the major human resources challenges faced by the science system at the time. In the executive summary, the report identified the following main reasons for the high dropout rate between bachelors and doctoral degrees:

1. Financial challenges constitute the single biggest obstacle to producing more postgraduate students in South Africa;
2. Financial challenges are more prevalent for black students at all levels in the system;
3. Low progression and retention rates are mainly due to part-time nature of studies (which is related to the lack of funding for full-time studies);
4. Students in the natural sciences (where larger proportions study full-time) have significantly higher progression and completion rates; and
5. Various factors influence student choice about continuation and discontinuation of studies but the main reason (again) is availability of funding followed by family considerations. Choice of university and degree programme at all levels is mostly informed by academic reputation and quality considerations (as well as employability factors).

In closing, it is worth pointing out that there are currently numerous initiatives, programmes and strategies either being implemented or designed at the DSI, NRF and DHET which aim to address the challenge of retaining local talent. However, in our assessment these initiatives are not necessarily clearly aligned or being coordinated adequately. It seems, for instance, that different approaches are being followed by the different

departments and agencies in terms of support for emerging scholars and early career academics; that there does not seem to be any coordination across these departments in establishing a system to track masters and doctoral graduates; and that the role of USAf and the CHE in these initiatives is not clear.

5.3 Attracting foreign talent to South Africa

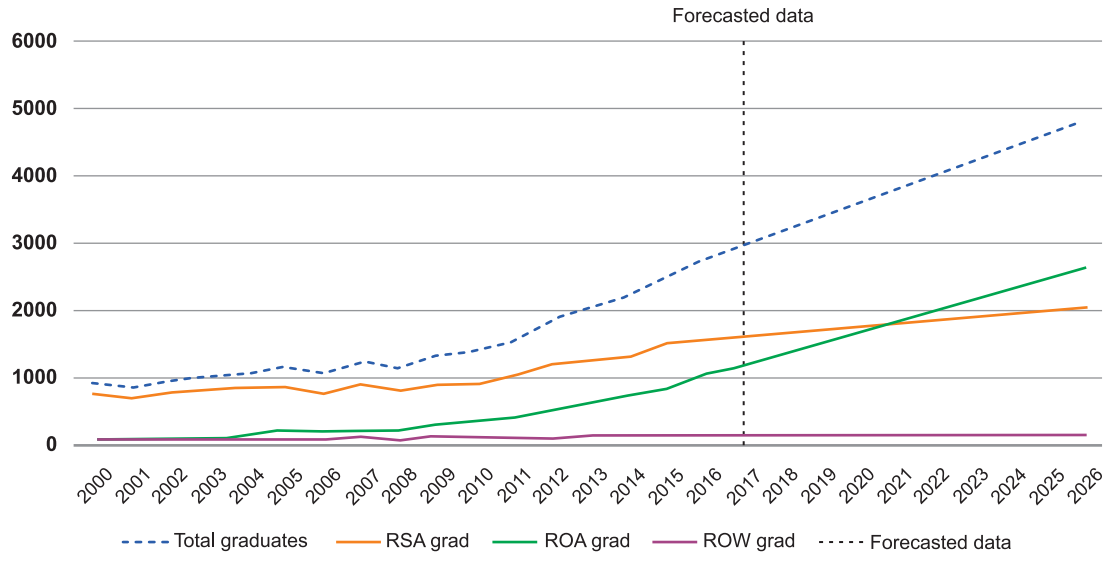
There is only one reference in the NRDS to **attracting foreign talent** (with specific mention of increased numbers of post-doctoral fellows) and it is found within the context of a discussion on internationalisation. There is no reference to an international strategy or programme in either document. However, considerable resources have been expended on a wide range of bilateral and multilateral S&T agreements in support of increased international (especially African) cooperation and collaboration.

As indicated in CREST's the *State of the South African Research Enterprise* report, South Africa has indeed managed to attract foreign talent in recent years, and specifically at the masters and doctoral levels. The statistics attest to the fact that South Africa has once again become a destination for migrant students from Africa, on a far larger scale than before apartheid. This increase is in part driven by the Southern African Development Community (SADC) Protocol on Education and Training which removes barriers to the free movement of researchers and students in higher education across the region. The protocol requires member states to allocate up to 5% of their university places for SADC students and to charge them domestic fees. But this trend has also been stimulated by increasing number of students from Africa not being able to afford the high student fees in Europe and North America.

Between 2000 and 2017, a total of 28 686 doctoral students graduated from South African universities. Of these, about two thirds were South African nationals and slightly more than one quarter (26%) were from the rest of Africa (RoA). But, the real growth in doctoral graduation output is driven by students from the rest of Africa. The rate of increase for RoA students (17%) has been nearly three times faster than the rate of increase for South African students. Hence, by 2017 doctoral graduates from the rest of Africa already constituted 37% of all graduates compared to South African nationals, who constituted 57% of all graduates. It is mainly because of the increased rates in inbound mobility of doctoral students from the rest of Africa that we have witnessed the steep increase in the number of graduations over the past 10 years, and why it now seems realistic to expect that we will reach the national target of producing 5 000 PhDs by 2030.

The graph below presents a forecasting of the expected numbers of doctoral graduates by 2026. According to this forecast, if current rates of growth continue, doctoral students from the rest of Africa will surpass the number of graduates born in South Africa in 2020/2021. A much more alarming result is that the number of South African doctoral graduates have already started to plateau and are growing at slower rates.

Figure 18: ARIMA forecasting of doctoral graduates disaggregated by region



The data on the internationalisation of postgraduate students show that doctoral students from the rest of Africa constituted between 35% and 45% of all doctoral graduates in 2017 (in some subfields this proportion is much higher). And has we have shown, the CAGR[121] values show that in each of the six main science domains, the rate of increase in students from the rest of Africa is much higher than that for South African students (in engineering, five times higher). In some cases, the CAGR for South African students is now zero (humanities). If these trends continue, doctoral graduates from the rest of Africa will, within the next three years, be the majority in most science fields, but will increasingly not qualify for any financial support.

Against the backdrop of these trends, it is particularly disappointing that the NRF has released a new funding policy that does not seem to appreciate the importance of attracting foreign talent to the country. In the new funding policy framework, it is stipulated that NRF scholarships will in future be allocated as follows: 95% to South African citizens and permanent residents and 5% students from SADC countries and the rest of the world. Given the experience in the rest of the world regarding the contribution of foreign doctoral students and post-doctoral fellows to the higher education and STI system, it is mind-boggling that the NRF would set a quota of only 5% for support of students from the rest of Africa, given that they constitute more than 40% of all current doctoral enrolments. This policy and its intent are at odds with international experience regarding the 'brain drain' and 'brain circulation'.

Already in 1999, Annalee Saxenian published an extensive report[122] on the economic contributions of skilled immigrants to California's economy. The study focused on the social, ethnic and economic networks of new US immigrants. One of her most interesting findings was that Chinese and Indian engineers ran a growing number of Silicon Valley companies started during the 1980s and 1990s, and that they were at the helm of 24% of the technology businesses started from 1980 t0 1998.

> *In a subsequent paper on the impact of foreign students on innovation in the US (especially the establishment of high-technology companies in Silicon Valley) Saxenian (2005: 36)[123] reminds us that "the migration of talented youth from developing to advanced countries was viewed in the post-war decades as a 'brain drain' that exacerbated international inequality by enriching already wealthy economies at the expense of their poor counterparts.". She quotes from a classic textbook on economic development[124]:*

The people who migrate legally from poorer to richer lands are the very ones that Third World countries can least afford to lose, the highly educated and skilled. Since the great majority of these migrants move on a permanent basis, this perverse brain drain not only represents a loss of valuable human resources but could also prove to be a serious constraint on the future economic progress of Third World nations.

Saxenian then refers to data from the 1990 US Census which shows that 2.5 million highly skilled immigrants, excluding students, came to the US after the Second World War. But, more importantly, she writes[125]:

> *Much of the movement of skilled individuals from developing to advanced countries during the latter part of the twentieth century has involved migration to the United States, specifically Silicon Valley. The region's technology producers grew very rapidly from the 1970s through the 1990s, absorbing scientists and engineers voraciously and irrespective of national origin. Tens of thousands of immigrants from developing countries, who had initially come to the U.S. for graduate engineering education, accepted jobs in Silicon Valley rather than return to their home countries, where professional opportunities were limited. By 2000, over half (53%) of Silicon Valley's scientists and engineers were foreign-born. Indian and Chinese immigrants alone accounted for over one-quarter of the region's scientists and engineers, or approximately 20,000 Indian and 20,000 Chinese (5,000 Taiwan- and 15,000 Mainland-born) engineers.*

The initial 'brain drain' from these countries in subsequent years became a 'brain circulation' as many of the qualified scientists and engineers returned to their home countries (Israel, Taiwan, India) and transferred their knowledge and skills to the establishment of new companies, firms and institutes (ibid: 37):

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[121] Compound Average Annual Growth Rate.
[122] Saxenia A. 1999. Silicon Valley's new immigrant entrepreneurs. UC San Diego Working Papers, No. 15.
[123] Saxenian A. 2005. Circulation: Transnational communities and regional upgrading in India and China. Studies in Comparative International Development, Summer 2005, 40(2): 35-61.
[124] Saxenian, 2005:p.36
[125] Ibid, p. 36

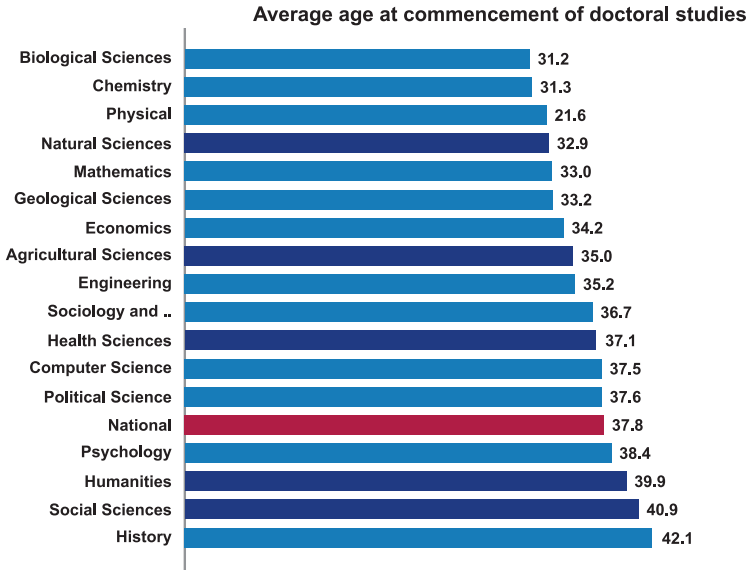
The spread of venture capital financing provides a window into this process. In the early 1980s, returning immigrants began to transfer the Silicon Valley model of early-stage high-risk investing to Taiwan and Israel, locations that U.S. venture capitalists typically had neither interest in nor the ability to serve. Native-born investors provided the cultural and linguistic know-how needed to operate profitably in these markets. In addition to capital, they brought technical and operating experience, knowledge of new business models, and networks of contacts in the United States. Israel and Taiwan today boast the largest venture capital industries outside North America, and both have high rates of new firm formation and growth. Israel is now known for software and Internet firms like Mirablis (an instant-messaging program developer) and Checkpoint (security software); Taiwan has become a center of leading edge personal computer (PC) and integrated circuit (IC) manufacturing with firms like Acer Technology Ventures (PCs and components) and TSMC (semiconductor foundry.) All have relied on returning scientists and engineers as well as a new breed of transnational venture investors.

In a 2018 policy paper, Andersen[126] makes the same point about the huge contribution of foreign students to technology development, business and innovation through a study of America's biggest start-up companies:

The research finds that 55%, or 50 of 91, of the country's $1 billion start-up companies had at least one immigrant founder. This illustrates the increasing importance and contributions of immigrants to the U.S. economy. A 2006 study conducted with the National Venture Capital Association (NVCA) identified an immigrant founder in 25% of venture-backed companies that became publicly traded between 1990 and 2005, while a 2013 NVCA study found immigrants started 33% of U.S. venture-backed companies that became publicly traded between 2006 and 2012. A March 2016 NFAP study found that immigrants started 51% or 44 of 87 of America's start-up companies valued at $1 billion or more and were key members of management or product development teams in 71% or 62 of 87 of these companies. ***Nearly one-quarter (20 of 91) of the billion-dollar start-up companies had a founder who first came to America as an international student.***

Another criterion for postgraduate funding included in the NRF's new funding policy is that all masters students must be 30 years or younger and doctoral candidates 32 years or younger in order to qualify for scholarship funding. These new eligibility criteria do not correspond with the reality. The graph below presents the average age of cohorts of doctoral students (2015 data) for a range of scientific domains. It is clear that the implementation of the new NRF policy will effectively exclude doctoral candidates from the vast majority of scientific fields from receiving bursaries!

Figure 19: Average age of doctoral candidates at commencement of doctoral studies



If one disaggregates the data on average age of commencement for masters and doctoral enrolments by race and scientific field, the picture changes for the worse. The table below shows that the new funding policy will in fact affect South African black students more than white students, since the average age of South African black students is higher in the majority of scientific fields. As far as masters' students are concerned, the majority in

[126] Andersen S. 2018. *Immigrants and Billion-Dollar Companies.* National Foundation for American Policy.

the health sciences, humanities and social sciences are, on average, over the median qualifying age of 30. Doctoral students in all fields, except for the natural sciences, are way above the qualifying age of 32. And, nearly in every case, the data shows that these trends apply more to black than to white students.

Table 5: Average age of commencement of masters and doctoral degree by scientific field and race (2017)

Scientific field	Agricultural sciences		Engineering, Architecture and Built Environment		Health Sciences		Humanities		Natural Sciences		Social Sciences	
	Black	White	Black	White	Black	White	Black	White	Black	White	Black	White
Masters	28	28	30	28	33	31	34	32	28	28	35	33
Doctoral	34	35	35	35	38	37	41	40	32	32	42	41

This is not a new result as CREST's study on the retention and throughput of postgraduate students in South Africa already identified this as a serious problem in the system. Because of financial challenges, black students are more likely to interrupt their postgraduate studies at every exit point in the academic pipeline (from honours to masters to doctoral). The result is that they commence their next postgraduate degree at increasingly higher age levels and – which is a corollary of this – then take longer to complete their degrees. The simple reason for this is that the majority of these students are studying for their masters and doctoral degree while in employment.

These two examples clearly illustrate that the NRF's new policy is **not** based on the factual evidence and historical trends at hand. With regard to the quotas now earmarked for non-South African students, the new policy in fact contradicts every other policy and strategy regarding internationalisation produced by the DST and DHET over the past two decades, where the explicit goals have been to increase and expand cooperation and collaboration with researchers and scientists in the rest of Africa.

5.4 The imperative to transform the human resources base for S&T

The imperative to **transform the human resource base** for S&T has been a key element of every higher education and S&T policy and strategy since 1994. Various initiatives by the DST, NRF and DHET were launched to address this challenge. These include new funding programmes (such as Thuthuka at the NRF), a variety of programmes under the University Capacity Development Plan of the DHET, as well as interventions to support black and women emerging scholars and early career academics at most universities.

CREST has published numerous reports over the past years that show that the higher education and science system has been transforming, with (South African) black and women students, staff and researchers increasingly participating and contributing to the production of science. In our most recent report,[127] we presented various analyses that show that the research and postgraduate enterprise has made great strides in becoming more inclusive of women and black academics. The following four graphs from this report illustrate these transformational shifts in the system:

1. The proportion of doctoral graduates increased from 25% in 2000 to 39% in 2015 but with significant field differences (Figure 20);
2. The proportion of female NRF grant holders increased from 20% in 2002 to 36% in 2015 (Figure 21);
3. The proportion of black NRF grant holders increased from 13% in 2002 to 31% in 2015 (Figure 22); and
4. The proportion of black-authored papers in accredited journals increased from 16% in 2005 to 29% in 2016. (Figure 23)

It is most likely, given the slopes of all of the curves, that further analyses of more recent data will reveal that these trends are continuing.

[127] Mouton J, Basson I, Blanckenberg J, Boshoff N, Prozesky N, Redelinghuys H, Treptow R, Van Lill M & Van Niekerk M. 2019. *The State of the South African Research Enterprise*. Stellenbosch: SciSTIP.

Figure 20: Change in proportion of black South African doctoral graduates (2000 and 2015)

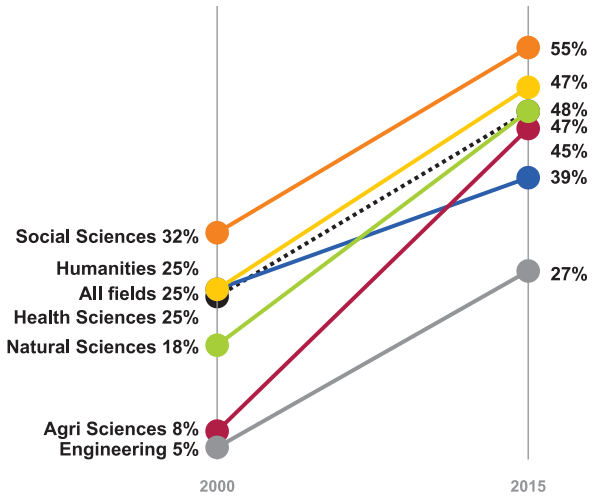


Figure 21: Proportion of female grant holders as a share of all grant holders: 2002 and 2015 compared

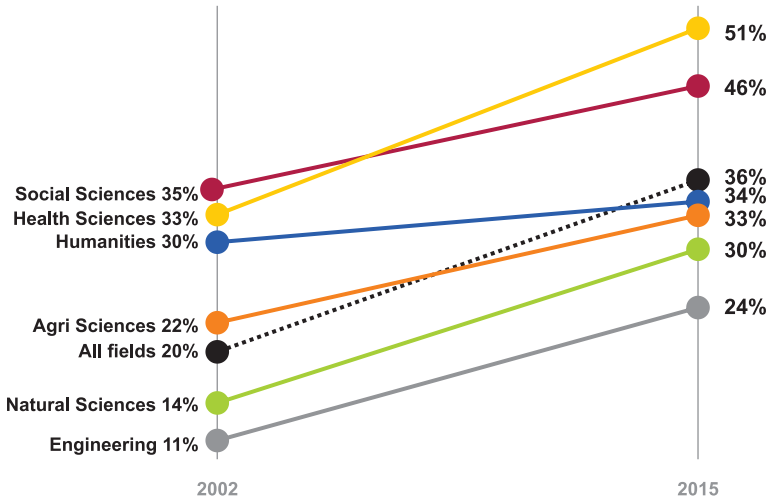


Figure 22: Trends in proportion of (South African) black grant holders: 2002 and 2015 compared

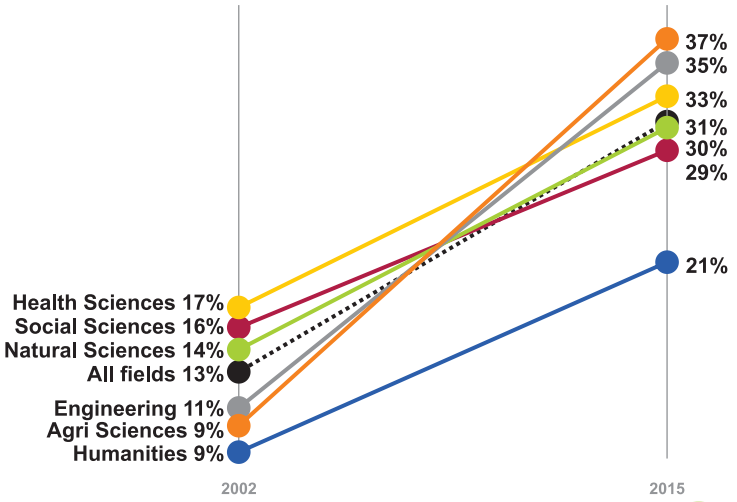
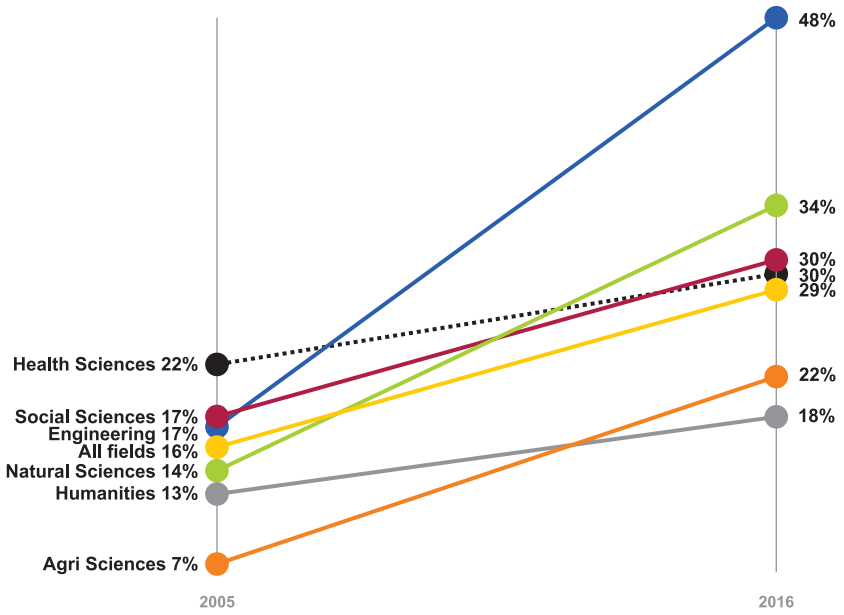


Figure 23: Change in proportion of black authors (2005 and 2016)



The general positive trends towards a transformed STI system – especially as far as race is concerned – is now well-established. The picture with regard to gender is slightly more complicated as female participation in the science system has increased significantly in some areas (e.g. in benefitting from NRF funding or in enrolments and graduations at university), but in other areas (such as contribution to scholarly publication) less so. In addition, and not surprisingly, we have found differences in the 'transformation rates' of blacks and women according to age, rank, scientific field and discipline, and institution.

However, what is not being investigated in any depth is how these trends are exhibited within individual institutions (universities, science councils and national facilities). Neither, as far as we are aware, has there been any assessment of how the different funding instruments of the NRF, Medical Research Council and the Water Research Commission, as well as other interventions aimed at establishing a more inclusive higher education and STI system, have contributed to the trends that we witness.

5.5 Recommendations

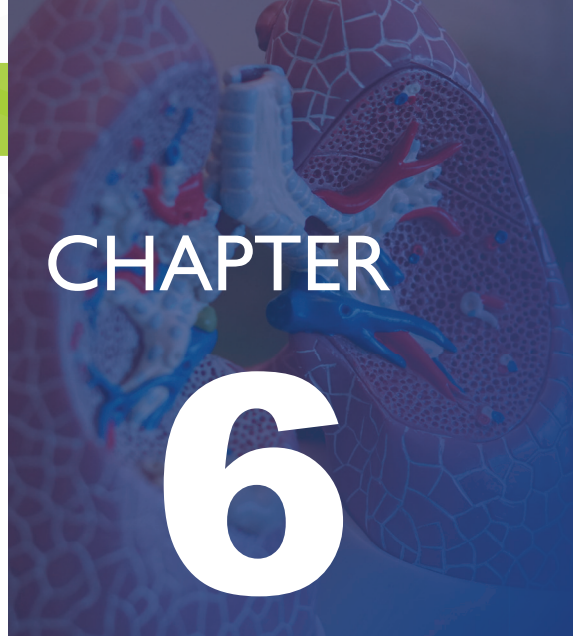
Recommendation:
An in-depth scoping and impact assessment study of the existing human resources interventions for S&T should be conducted

There are currently numerous strategies, interventions and funding instruments being managed by the DSI, NRF, DHET, MRC, WRC and other departments and agencies that refer to the need to expand and transform the human resources base for science and innovation in the country. But in our assessment, there is still insufficient inter-departmental and inter-agency coordination between these different initiatives. There is also no central database on these interventions and the financial investments that are currently being made in this area. We therefore recommend that (1) a definitive scoping study is undertaken of all of these interventions (including funding instruments); (2) that the results of such a scoping study be used as the point of departure for developing an integrated and transversal strategy for the expansion and transformation of human capital for the NSI; and (3) a that comprehensive impact assessment is undertaken of these initiatives.

Recommendation:
An integrated and updated human resources strategy for S&T should be developed and implemented

The omission of a dedicated human resources strategy for S&T in the NRDS, and especially the TYIP, was in our view an oversight. Even though various initiatives were being planned and implemented,

none of these were driven directly by the DST. With many stakeholders operating in this space, it was even more important that a coordinated and dedicated strategy for the science system should have been developed. The need for an HRD strategy had already been raised in the White Paper of 1996, in which specific reference was made to the fact that DACST had been assigned the responsibility of "bringing the perspective of S&T to each of these programmes" (DACST, 1996: 38). But it was only 13 years later that this was given effect when, in the revised version of the national HRD Strategy (2009), a clear division of labour between DST and DHET regarding strategies and programmes related to HRD was made. In 2016, the DST published its own strategy: The Human Capital Development Strategy for Research, Innovation and Scholarship. In our discussion of this strategy we pointed out that it is a much improved strategy (compared to the HRD Strategy of 2009) but that it still requires further refinement and updating (especially of targets and indicators). Our recommendation thus is that a revised human resources strategy for S&T be developed. Such a revised a strategy must also ensure proper alignment with other existing strategies (such as the University Capacity Development Programme at DHET and the new funding policy of the NRF). This strategy must also align with the system-wide M&E framework proposed above (section 4.2) so as to ensure appropriate monitoring and evaluation of the strategy in the future.



CHAPTER 6

SCIENCE AND KNOWLEDGE GENERATION: SCIENCE MISSIONS

6.1 Reflections: science domains and science missions

The core narrative related to the advancement of science in both the NRDS and TYIP is grounded in the geographic and historical advantage that South Africa has in a number of scientific fields. The underlying premise of this narrative is simple: invest in and nourish and expand those scientific fields in which there is a comparative strength in terms of human resources, accumulated knowledge and scientific infrastructure. It is therefore not surprising that both documents identified fields such as astronomy, palaeosciences, indigenous knowledge systems, biodiversity, infectious diseases, deep mining and other 'strong' fields for specific attention.

The most explicit set of interventions were reserved for astronomy, palaeosciences, biodiversity (environmental sciences including marine and Antarctic research and climate change), and IKS. Our review has shown that the specific focus on these fields has produced demonstrable gains in scientific knowledge output, human resource capabilities and infrastructure. In fact, as Saul Dubow[128] has recently argued, the investment in these fields cannot simply be reduced to interventions to advance scientific knowledge production; many of these areas constitute the frontiers of scientific endeavour in the country (Dubow, 2019: 658):

> *In the post-apartheid era, the frontiers of science in South Africa have been extended by taking advantage of the country's deep history and unique geographical position. In Antarctic polar research, climate change and environmental concerns are foremost priorities for study; in human palaeontology and rock art, South Africa figures as a unique entry-point to deep time and the emergence of humanity from hominids and pre-hominids; with the MeerKAT and SKA telescopes, major efforts in radio astronomy are being made to inspire interest in cosmology and give substance to the promise of African-based science and technology.*

This applies even more to the case of astronomy where a series of inter-locking interventions with substantial government financial support and visible championship produced significant outcomes (ibid: 687):

> *The advance of astronomical science rooted in strong international collaborative links and with direct support from the government has been a notable feature of 21st-century South African scientific policy. New graduate schemes, conferences, bursaries, funded MSc programmes and initiatives like the National Astrophysics*

[128] Dubow S. 2019. 200 Years of astronomy in South Africa: From the Royal Observatory to the 'Big Bang' of the Square Kilometre Array. *Journal of Southern African Studies*, 45(4): 663-687.

and Space Science Programme, the Office for Astronomy Development and the African Institute of Mathematical Sciences are all part of an integrated effort to build local capacity and pursue broader developmental objectives. Key support for astronomy demonstrated by politicians such as Naledi Pandor and scientists with histories of political activism such as Rob Adam and Bernie Fanaroff has helped to translate the non-racial traditions of the ANC into the aspirations of scientific internationalism and developmentalism. Their skillful and determined advocacy has been crucial in winning local and international support for the SKA.

This leads Dubow to conclude on a rather sobering note (ibid: 687-688):

With the abandonment of South Africa's nuclear weapons programme, astronomy has become the country's premier 'big science' commitment…. In post-apartheid South Africa, some of the same questions pertain. Is South African astronomy still mostly attractive to international consortia on account of the special access that it allows to the skies of the southern hemisphere? To what extent are astronomical prestige projects contributing to the expansion of indigenous South African scientific capacity? Is Africa really ready to 'compete with the world' in the realisation of big scientific projects…? Will the SKA run into local resistance, as has happened in Mount Graham, Arizona, and now in Hawaii, where a major international observatory precinct on the Mauna Kea mountain top has become a major source of conflict between scientists and local communities over land rights and sacred sites? …The biggest set of questions are very much a product of post-apartheid promises and expectations: given the huge investment in government resources, is the SKA likely to meet the social and developmental promises that constitute a crucial element of its prospectus and so meet local community expectations as well as those of the international scientific community? Exciting as the prospects of the SKA undoubtedly are, there are troubling indications that it may not.

The initial formulation of the strategies for the four **science domains** included in the NRDS focused on developing these fields into world-class science domains as well as developing the future R&D capacity in these fields. The focus was on basic science founded on our geographic and accumulative knowledge advantage. This sentiment is clear expressed in the following statement in the NRDS (DST, 2002: 16): "One way to achieve national excellence is to focus our basic science on areas where we are most likely to succeed because of important natural or knowledge advantages. In South Africa, such areas include astronomy, human palaeontology and indigenous knowledge."

However, the subsequent developmental trajectories for each of these four fields show that it would be more appropriate to describe these as science **missions** which increasingly incorporated other features under the remit. Each of these four scientific domains – in varying degrees – involved the establishment of new research centres and research chairs, investment in building new and strengthening existing infrastructure (e.g. new telescopes, Agulhas II), and the development of new technologies. This invariably led to the involvement of multiple agencies and stakeholders outside the science sector (various government departments, NGOs, museums, etc.) which, in turn, required increasing cross-departmental coordination of effort.

In addition, under the all-pervasive regime of new public management and the imperative for science to address socio-economic goals (as captured in the SDGs), all of these 'science missions' are increasingly required to contribute to innovation and socio-economic outcomes. Examples of the latter are:

- *Astronomy:* To ensure that the advantages of astronomy, such as Big Data and the transfer of skills, are translated into socio-economic benefits for South Africa.
- *Palaeosciences:* Make South Africa the destination of choice for palaeo-tourism by building a network of site displays and interpretative centres which are managed in a socially responsible and sustainable manner
- *Marine and Antarctic science:* Contribute towards the creation of employment derived from innovation in the marine and Antarctic environments
- *IKS:* Promote IKS as an employment generator: The creation of businesses based on IK services resulting in long-term gainful employment opportunities in indigenous communities, thus assisting in poverty reduction.

In summary, what started out as an intent to promote world-class science in these fields, over the years morphed into science-led missions with an increasing focus on technology development and commercialisation

to produce socio-economic outcomes. This does not mean that the original intent of supporting excellence in science (and high level skills development) has been discarded. But it does mean a clear shift towards what Stokes[129] would call 'use-inspired' basic research, or what others have referred to as strategic research (basic research with medium- to long-term social outcomes and impact).

If our analysis is correct, it raises at least three 'tricky' questions:

1. The most obvious is the issue of the sustainability of the current financing levels for these science missions in the future.
2. A second issue speaks to the question of differentiation of purpose and mandate in the science system.
3. The third issue is whether this same approach – the science mission approach – can be applied more generally across other 'strategic' scientific fields.

As to the first question, the table below gives a very rough estimate of the financial investment in these four domains. Despite the huge discrepancies between astronomy and the other three fields, it is still evident that these four domains received disproportionately high amounts of investment compared to other science fields. Are these amounts sustainable especially if other science domains are identified for priority funding?

Table 6: Estimated funding for the four science domains identified in the NRDS and TYIP[130]

Science domain	Funding instrument	Timeframe	Total
Astronomy/SKA	Support to radio and optical astronomy	2014-2018	R70,735
	Infrastructure for the SKA project	2014-2018	R2,047,307
	R&D for the SKA project	2014-2018	R668,681
Palaeosciences	African Origins Platform (Research/ Equipment/ Infrastructure	2009-2017	R83,554,611
	Palaeo/Anthropology Trust	2009-2018	R16,400,000
	CoE in Palaeosciences	2013-2017	R45,256,313
Marine and Antarctic sciences	SA National Antarctic Programme	2009-2018	R130,322,097
Indigenous knowledge systems	IKS (NRF Funding)	2002-2018	R197,659,333
TOTAL			**R473,861,035**

The second raises questions about the future size and shape of the core institutions in each domain and their relationships with 'cognate' interventions. Stated differently: what exactly is the difference between advancing science in a specific domain, a science mission, and a grand challenge? A cursory reading of current debates in STI policy[131] shows that there is growing support for new forms of mission-oriented policies both in science and innovation. The distinctive feature of all mission-oriented policies is that their starting point is what we want to achieve in the medium- to long-term. What kind of outcomes – knowledge, technologies, innovations, socio-economic – are we aiming to achieve through such a mission? If the trend is increasingly to define the contribution of science in conceptualisations around grand societal challenges, one needs to (a) find a way to protect the space where basic research is undertaken, and (b) ensure that the integration of science missions in mission-oriented innovation policies is meaningful. This leads to the following point.

The third question relates to how to deal with other (equally) important strategic scientific fields. This issue was already raised in the 2017 STIIL report (DST, 2017: 25):

> *Historically, key fields of institutional research in South Africa have included the agricultural sciences, physical sciences, space science, health sciences, and social sciences, amongst others. While these fields of research and innovation will continue to provide powerful demand in the 21st century digital economy, demand is growing worldwide, particularly on the African continent, for knowledge production in ICT goods and services, software development, 3D printing and manufacturing, Internet of things, and*

[129] Stokes D. 1997. *Pasteur's Quadrant – Basic Science and Technological Innovation*. Brookings Institution Press.
[130] These amounts are almost certainly underestimates of actual expenditure on the four domains, especially because of lack of funding data for the marine and Antarctic science fields.
[131] See, for example: Mazacutto M. 2018. *Mission-Oriented Research and Innovation in the European Union: A problem-solving approach to fuel innovation-led growth*. Brussels: European Commission.

in the underlying fields of basic research that support these applications. … Similarly, demand is growing in the health and environmental sciences and technologies, including in addressing drug resistance, energy generation and storage, water conservation and availability, and the wide range of sciences that inform future environmental sustainability and security of food and livelihoods. Other challenging fields of research relate to science and technology for the broad manufacturing sector and for fostering the ocean economy, an important focus for South Africa with its 2 798 km of coastline, significant ocean-based economic activity, and potential trade within the Indian Ocean Rim Association community. Research in the educational sciences will require much greater research attention and innovation … Many of these fields are already highlighted as key focus areas in the relevant policy documents (RSA, 2012; DST, 2008), though many require attention as emerging fields of science and technology innovation that have not historically been a major institutional focus or site of investment.

The same report also questions whether the five grand challenges identified in the TYIP can indeed be deemed the most important (ibid.: 40):

Global initiatives such as the Square Kilometre Array have started driving development that leads to changes in society and innovation. The SKA is an example of good leadership in innovation with diverse players, including government (national, provincial, and local), business, international players, and researchers forming a cohesive front that provided the necessary momentum to make it happen. Similar innovation initiatives or directives are needed to tackle South Africa's real Grand Challenges, e.g. food security. The five Grand Challenges identified by the DST, however, are not necessarily the most pressing current and future challenges facing South Africa.

As a 'counterbalance' to the increasing 'appropriation' of scientific disciplines in science and innovation missions, strategic (SDG-led) research and grand challenges, one has to also reflect on how the basic sciences can be protected and strengthened. This brings us to the DSI's recent initiative to establish a basic sciences platform.

6.2 The basic sciences platform initiative

An important national initiative in the advancement of science and knowledge generation in the country post-dates the TYIP. In 2016, the DST published a framework document entitled *Basic Sciences Development and Support Framework.* This framework document presents the following argument in support of the basic sciences (DST, 2016: 6):

While there has been a strong focus on developing emerging research areas (such as Nanotechnology, Biotechnology, etc.) and technology intense applied sciences (Space Science, Information and Communication Technology (ICT), and Energy, the support to the basic science disciplines (Biological Sciences, Chemistry, Physics, Mathematics, Statistics, Computer Science, Geological Sciences) is currently unstructured and requires interventions to ensure their sustainable development.

The framework document further argues that current initiatives to support and develop the basic sciences are unstructured and in some instances insufficient. As a result (ibid: i):

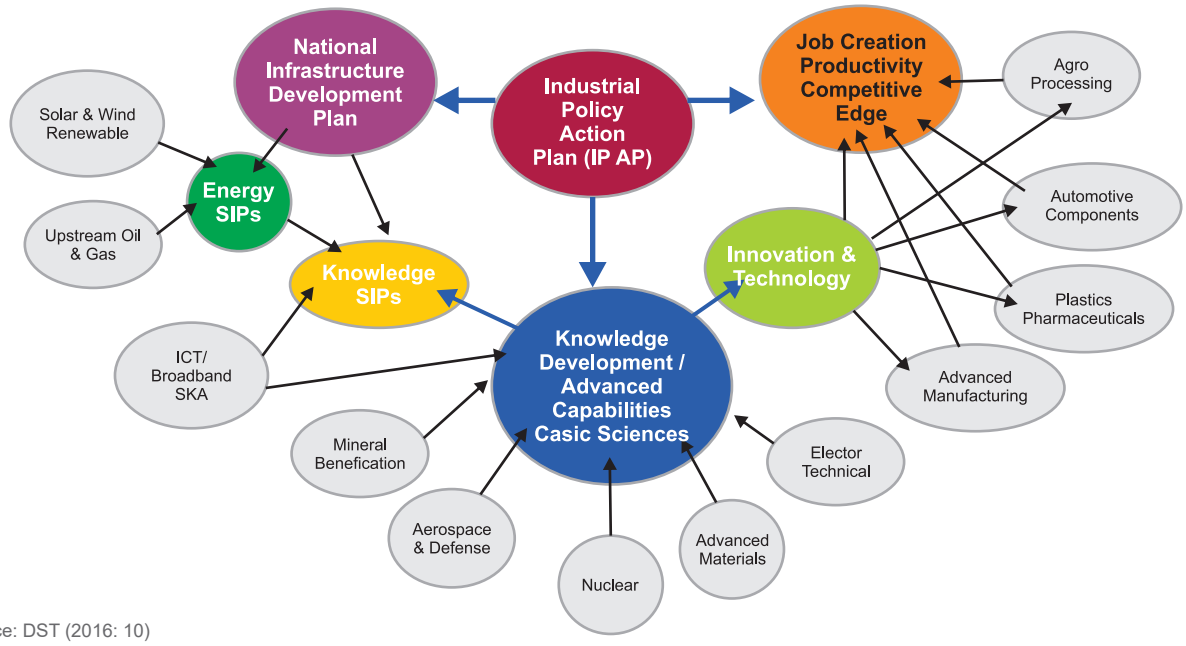
… the related disciplines and the associated science, engineering and technology (SET) fields they underpin are negatively affected. Targeted interventions are required to ensure sustainable development and support of the BS. In this case, the Basic Sciences refer to the scientific disciplines where fundamental knowledge about the natural and physical world is built and maintained, and covers chemistry, physics, mathematics, and statistics, as well as computer, biological and geological sciences (clustered broadly as physical, mathematical, and life sciences).

The main mechanism through which this support and development will be undertaken is through the established of a national basic sciences platform – the South African Basic Sciences Platform (SABSPlat) (ibid.):

The platform will enable an interface between all key stakeholders in the Basic Sciences that can (a) support the DST and NRF in conceptualising support programmes within the DST remit, and (b) enable the stakeholders to develop collective responses to other issues of generic relevance, e.g., curriculum and teacher development. The support programmes will primarily focus on human capital and research capacity development in the BS.

It is important to emphasise that the establishment of the SABSPlat is not driven by a traditional defence of basic and fundamental science for the sake of science. It is clear from the Framework document that the main rationale is the necessity of supporting the basic (natural and social) sciences because of their essential role in producing the required human capabilities and scientific knowledge that underpin key technologies, which ultimately results in socio-economic benefits. Nevertheless, the initiative should be applauded as it sends an important signal to the scientific community. The figure below illustrates the envisaged interaction between the basic sciences and other sectors.

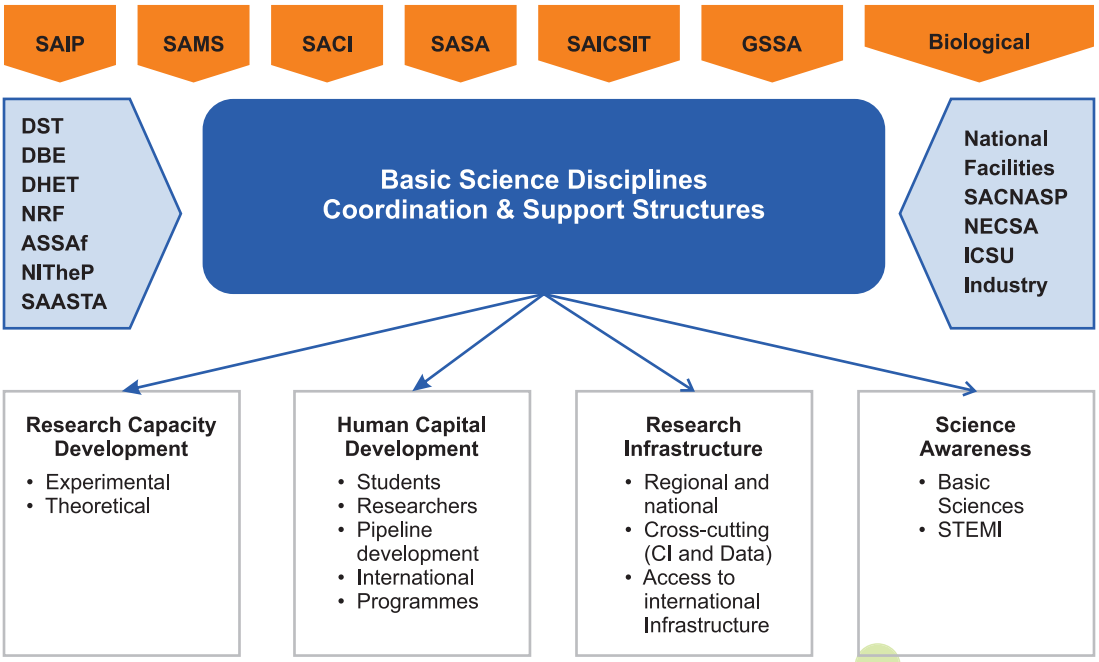
Figure 24: The basic science platform



Source: DST (2016: 10)

Finally, the modus vivendi of the proposed platform is to address a number of goals around capacity development, human capital development, research infrastructure and science awareness, together with different stakeholder groupings (government departments, national facilities and professional societies and associations).

Figure 25: Structure of the South African Basic Science Platform (SABSPlat)



Source: DST (2016: 21)

In 2017, DST commissioned CREST to undertake a series of seven scientometric studies of the basic science disciplines identified: Biological sciences, Geological sciences, Chemistry, Physics, Computer science, Mathematics, and Statistics. The final reports of these seven fields were delivered to the DST in March 2019. Subsequent to this commission, CREST was asked in June 2018 to undertake similar reviews of six basic social sciences: History, Sociology, Economics, Psychology, Philosophy, and Political Studies. The reports of these reviews are currently being finalised to be delivered to DSI by the end of April 2020.

The aim of these scientometric studies was to produce an evidenced-based profile of the strengths and weaknesses of each discipline. Four main dimensions of each field were assessed: (a) NRF investment, (b) capacity and diversity of academic staff, (c) academic pipeline, and (d) research performance. A total of 84 indicators were populated from diverse data sources, and a field vulnerability index (FVI) was constructed to identify the areas in which the fields are weak and require support and development. A strength of this approach is not only the fact that the work of the platform will be informed by reliable and recent data about each field, but also that extensive engagements have commenced where the findings and recommendations of these reports have been discussed with key stakeholders in each field.

6.3 Recommendations

Recommendation:
Conduct a study into the optimal size and number of the two flagship science programmes

Although the CoE and SARChI programmes have been reviewed by the NRF, we recommend that a much more comprehensive study is conducted that goes beyond the past reviews to include questions about the optimal size and shape of these programmes. Such a review, which should be commissioned externally, should address issues such as: whether all CoEs and research chairs should have identical key performance areas (we believe that there are good arguments for a more differentiated approach); and whether there should be a clear pathway for some CoEs to become national institutes and, similarly, for clusters of research chairs to become a national centre or network of excellence. This study should also explore how the CoEs and SARChI chairs could be better linked to other public research institutes in government as well as to R&D units in industry.

Recommendation:
Investigate the establishment of clusters or platforms of research chairs around common societal challenges

There are currently more than 200 active research chairs. With some exceptions, research chairs have been awarded on a competitive basis with little directionality from the NRF. But it is also clear that 'clusters' of chairs have emerged over time. As far as we know there is currently no mechanism to ensure that knowledge generated by chairs in such clusters are shared in a systematic fashion – either with each other and/or with other stakeholders in governments and industry. We therefore recommend that an investigation be undertaken (which would include all the chairs and relevant stakeholders) into the feasibility of establishing a number of **Research Chair Clusters** in those areas which correspond to the societal challenges that South Africa faces currently and in the future.

Recommendation:
Expand the range of basic science disciplines to be included in the DSI basic sciences platform

A glaring omission in the current list of basic science disciplines is the exclusion of basic health sciences. We strongly recommend that the DSI – in cooperation with the Department of Health and the MRC – identifies these disciplines (such as virology, genetics and heredity, cardiovascular and respiratory diseases, physiology, immunology and pathology) for inclusion in the platform, and commissions' comprehensive scientometric studies of these fields as well.

Recommendation:
Use the baseline data to track the 'performance' of the basic sciences disciplines over time

At the time of writing this report, CREST has produced 12 scientometric studies of basic sciences and social sciences fields. As indicated above, these are comprehensive assessments (using 84 indicators). The scientometric assessments of these fields constitute a kind of baseline for where these disciplines are in terms of various dimensions. Our recommendation is that these assessments (including other fields) be continued and updates on an annual or bi-annual basis, and be integrated into the overall implementation plan for the M&E framework for the STI system.

In addition to these general recommendations about the science missions, our review has also identified recommendations particular to the current science missions.

Recommendation:
Conduct a systematic evaluation of the socio-developmental benefits of the investment in astronomy

Arguably, astronomy is **the** success story of the research and innovation system. However, the actual benefit accruing to local communities is more difficult to establish, the more so as the Square Kilometre Array (mid- and high-frequency array) has yet to be constructed, and much astronomy research is conducted remotely rather than primarily using local infrastructure. We therefore recommend that a systematic evaluation be undertaken of the extent to which the investment in astronomy has produced the expected societal and development outcomes.

Recommendation:
Conduct a comprehensive review of the implementation and outcomes of the Palaeosciences strategy

Serious consideration should be given to expanding the CoE in Palaeosciences to become something akin to a 'national institute' which functions across the entire country. The funds provided by the NRF to the CoE have added much value. Additional and increased funding for a new palaeosciences national institute with a broader mandate would add value to the palaeosciences community and to a broader public audience. Furthermore, a comprehensive review of the activities of the Department of Arts and Culture and the agencies responsible for heritage and museum management (such as the South African Heritage Resources Agency), as well as palaeo-tourism, should be conducted. The evidence suggests that the contribution of the Natural History Museums, and particularly the DAC, towards developing the palaeosciences in South Africa has been disappointing. Currently, the development of human capacity in the palaeosciences has been successful, but without the creation of entry-level positions for palaeoscientists, particularly at museums, the uptake of skilled graduates is lost. Finally, one of the planned interventions outlined in the South African Strategy for the Palaeosciences includes a review of the heritage legislation. Our review of the strategy found that the drafting of the legislation was done without consultation with the palaeosciences community, and that the current legislation severely hampers their research activities. We thus recommend that SAHRA act in consultation with palaeoscientists to ensure that the heritage legislation actively supports the activities of the palaeosciences community.

Recommendation:
Conduct an independent review of the Marine and Antarctic sciences strategy

Given the obvious complexities of the Marine and Antarctic Research Strategy as a multi-agency, multi-site set of interventions, we recommend that the DSI, in consultation with the other key stakeholders and implementing agencies, consider commissioning a comprehensive external review of the implementation and short-term achievements of the MARS. The strategy framework is sufficiently detailed to inform such a review.

Recommendation:

Conduct an external evaluation of the Indigenous Knowledge Systems Policy and its implementation

Given that 16 years have passed since the publication of the IKS Policy (2004), it is recommended that a strategy and associated implementation plan for IK/IKS is developed, and that a comprehensive, external evaluation of the existing IKS programme of interventions is undertaken, in order to inform the way forward in this domain. These will need to take into account the very cross-cutting nature of IK/IKS, relating as they do to a variety of societal sectors, policy areas and scientific fields – from the arts and cultural heritage, to agriculture, pharmacology, bio-innovation, and intellectual property rights – and involving a variety of stakeholders across different communities.

FROM TECHNOLOGY STRATEGIES TO ENABLING AND CROSS-CUTTING TECHNOLOGY PLATFORMS

CHAPTER 7

7.1 The trajectories of the technology missions

The core of the NRDS is based on three pillars: innovation; SET human resources and transformation; and the creation of an effective government S&T system. In its discussion of the innovation pillar, the NRDS identifies a number of technology missions that "are critical to promote economic and social development" (DST, 2002: 16):

> *These include the two key technology platforms of the modern age, namely biotechnology and information technology. Two additional missions are technology for manufacturing and technology to leverage knowledge and technology from, and add value to, our natural resources sectors. Finally, we will establish a mission, technology for poverty reduction, to address one of the scourges of our age.*

Five technology strategies – biotechnology, advanced manufacturing, resource-based technologies, ICT and nanotechnology – were explicitly identified for support and development in the NRDS. Although the NRDS made reference to 'technology for poverty reduction', as far as we could establish no separate strategy was developed. Nevertheless, as we have shown in Volume 3 (Chapter 4), it is defined as a programme and substantial monies were allocated to it: R132.4 million between 2009/10 and 2014/15. Thereafter this 'programme' was renamed 'Innovation for inclusive development' and has since received R126.9 million.

The National Biotechnology Strategy (2001), which preceded the NRDS, was further given dedicated attention and funding, and would eventually become an integral part of the Bio-economy (Farmer to Pharma) Grand Challenge. We thus return to this domain in the next chapter on the grand challenges.

As far as the other four technologies are concerned, our review shows that each of these subsequently followed a very different developmental trajectory. Already at the time that the TYIP was published, the focus had shifted from a discussion of these technologies as clearly delineated and separate technology missions, to an emphasis on their role as cross-cutting enablers (together with human capital development and knowledge infrastructure) for the five grand challenges. This is clearly demonstrated in passages such as the following (DST, 2008):

> *South Africa must seize the opportunities now available in areas such as biotechnology, nanotechnology and the "hydrogen economy" to establish capabilities that will provide long-term,*

sustainable solutions in national priority areas such as health and energy, while boosting economic growth. (p13)

Over the next decade South Africa must work to become a world leader in biotechnology. Since the introduction of the first commercial genetically modified crops in 1995, more than 400-million hectares have been planted, 40 percent of which are grown in the developing world. And it is in the developing world where the need for biotechnological innovation to solve basic problems, from health care to industrial applications, is most apparent. (p20)

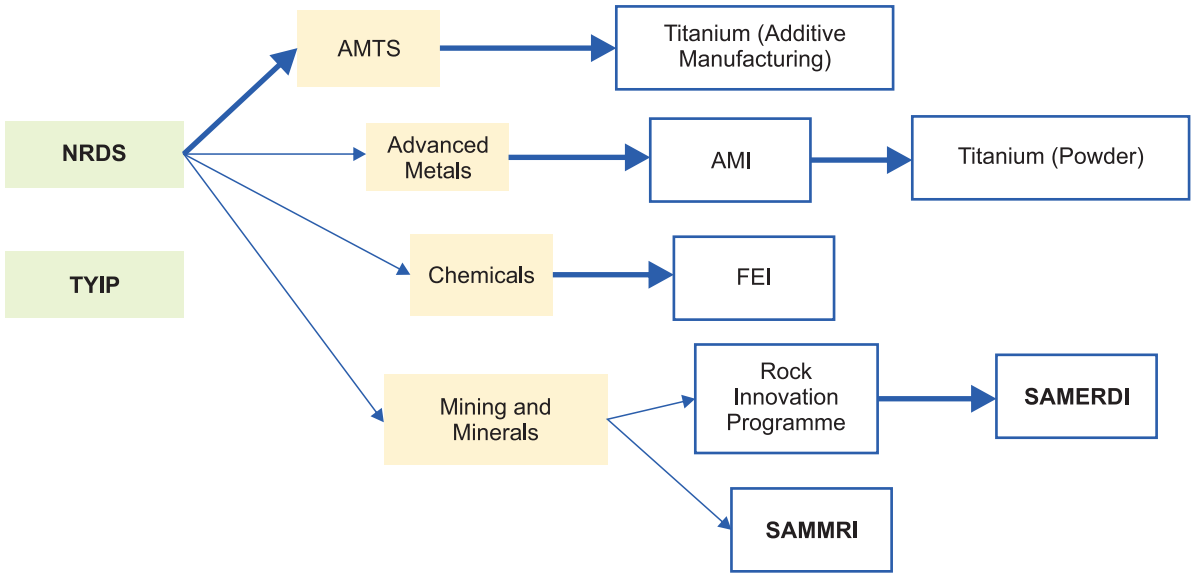
The shift in the narrative from the NRDS to the TYIP does not necessarily signify a shift in emphasis or importance. But it does demonstrate the difference between a more 'technocratic' – even 'linear' – approach to the role of technology in development (NRDS) to an approach where technology serves the demands for inclusive development in society (TYIP and the 2019 White Paper). This shift is analogous to the shift from defining technology in terms of clearly demarcated 'technology push-missions' to seeing technology as a cross-cutting and enabling platform in addressing societal challenges

We now turn to the three technology strategies which were explicitly identified in the NRDS and TYIP as such – advanced manufacturing and mineral beneficiation, ICT and nanotechnology (the latter in the TYIP) – and show how each of these subsequently followed a different trajectory.

7.1.1 Advanced manufacturing and resource-based technologies

In his review of advanced manufacturing and resource-based technologies, Walwyn (this report, Volume 5: Annexure 14) shows how, following the NRDS, a number of other industry-related programmes were implemented. These included the advanced metals initiative, technology localisation, the mining and metallurgy initiative, and the chemical industries strategy. Over time this led to "a complex web of strategies and programmes which have only a distant link to the original statements of the NRDS." For the purposes of this review, Walwyn separated these into four separate clusters, namely advanced manufacturing technologies, advanced metals, resource-based industries/beneficiation, and chemical industries.

Figure 26: Relationship between the NRDS and the subjects of the advanced manufacturing and resource-based technologies review



The intention of both the TYIP and NRDS to build local capability in R&D which could support and grow South African manufacturing and other sectors is shown in Figure 27. The process imagined a gradual separation of the technology user (in this case Eskom) from a dependence on international technology transfer.

Walwyn comments on the fact that the TYIP positioned R&D-led innovation (rather than technology transfer) as important in the technology missions, particularly those sectors already identified by other strategies as being core to the transformation of the economy from resource-based to knowledge-based, such as advanced manufacturing technologies, "smart" materials and metals, advanced ICT, 4th generation nuclear reactors manufacturing, and chemicals technology.

Figure 27: Evolution of innovation capability to support local sectors: Eskom as example

Total Dependence on International Technology Transfer	Partial Reliance on International Technology Transfer	Total Self-Reliance
Phase 1: International Vendors as Prime Contractors	**Phase 2:** Eskom Manages the Value Chain	**Phase 3:** Eskom Assumes Overall Responsibility
Opportunity Scanning	Increased Domestic Participation	Total Domestic Manufacture and Export

Growing Local Knowledge Base

Interestingly, the four 'sub-strategies' of advanced manufacturing technologies, advanced metals, chemical industries and mining/minerals form the core of the activities within the DST's Chief Directorate of Technology Localisation, Beneficiation and Advanced Manufacturing (TLBAM), which is part of Programme 5.

According to Walwyn, the initial absence of a detailed implementation plan for the NRDS objective of leveraging resource-based industries suggests that the DST did not place a high priority on this policy component. Instead, the Department chose initially to focus on emerging high-technology sectors which were minor players in the economy. Although this approach appears somewhat illogical in that there should be obvious advantages in building value chains closely associated with established sectors and raw material suppliers, it aligned with the dominant industrial policy perspective of the time which was defined by the terms 'resource curse' and 'the low value of extractive industries'. This approach to industrial development or technology-led economic development is exemplified by the initial flagship projects of the Advanced Manufacturing Technology Strategy (AMTS), incorporating Advanced Electronics, Advanced Lightweight Materials, and Advanced Production Technologies.

Subsequent policy perspectives have been more sympathetic towards beneficiation/value chain approaches. This change in policy has indeed also been reflected in the focus of the DST, which has shifted resources to building value chains in its more recent activities – although opinion on the validity of a beneficiation approach to industrial development remains divided, with several recent articles again calling for a revision of such strategies.[132] On balance, the DST has adopted a dual or mixed approach by supporting projects in value chain beneficiation (such as titanium, platinum and fluorspar) and in advanced manufacturing technologies (such as additive manufacturing). Seeking a balance between beneficiation and high-technology is perhaps the best strategy in the absence of clear opinion on how to focus industrial policy.

7.1.2 Information and communication technologies

In 2002, the NRDS declared ICT as a fundamental platform technology. The NRDS highlighted a number of specific foci for ICT, as well as intensification of ICT use in resource-based industries and manufacturing, and the use of earth observation (satellite and aerial) data to support government, industry and SADC in key areas. Other areas relevant to ICT would be microsatellite engineering and encryption technology.

[132] Kahn M. 2019. Industrial policy and innovation policy: Myths and realities. *TIPS Annual Forum 2019*, Midrand. Available: http://forum.tips.org.za/past-forums/forum-2019/papers-2019; Kaplan D. 2019. *South Africa's Industrial Policy: Time for a review and a rethink*. Johannesburg: Centre for Development and Enterprise.

The TYIP gave little advocacy to ICT or even information infrastructure, making only passing references to ICT in relation to topics such as contributing to improving health care delivery, addressing the innovation chasm through targeted public investment, and enhancing innovation and growth in priority sectors.

Six years after the publication of the DST's 2007 *Information and Communication Technology Research and Development and Innovation Strategy*, the DST/CSIR developed the 2013 *ICT RDI Roadmap: Towards Digital Advantage: Road mapping South Africa's ICT RDI Future*. The Roadmap is intended to provide "a coherent, comprehensive and flexible ten-year implementation framework to coordinate and manage ICT research and technology development nationally, regionally and in relation to our international partners" (DST/CSIR, 2013: 4). The central concept of the ICT RDI Roadmap is that of 'digital advantage', as described in the Foreword by the Minister of S&T:

> *The National Development Plan sees ICT by 2030 underpinning a dynamic, inclusive and prosperous information society and knowledge economy, in which a seamless information infrastructure will meet the needs of citizens, business and the public sector, providing access to a wide range of services required for effective economic and social participation at a cost and quality at least equal to South Africa's competitors. Such a situation, in which advances in ICT are used to strengthen economic competitiveness and enable an enhanced quality of life, is described as a "digital advantage", and the ICT RDI Roadmap was developed by the Department of Science and Technology, in partnership with the CSIR Meraka Institute, to guide South Africa to this state of digital advantage.*

The introduction by the DST Director-General further elaborates on this notion (ibid: 3):

> *Digital Advantage will enable South Africa to become a significant player in the global ICT RDI arena, provide more targeted engagement with industry, focused international collaboration, more comprehensive and transparent monitoring of investment and achieving impact, such as jobs and business creation, contribution to GDP, societal impact and positioning South Africa for strategic advantage.*

More than twenty years ago, the ICT Panel that formed part of the National Research and Technology Foresight study in early 1996 commented on the 'dual' nature of ICT, referring to it as a "a scientific discipline and industry in its own right, as well as cutting across all other sectors" (DACST, 1999: 48).[133]

The transversal and ubiquitous nature of ICT in the modern age – captured in such terms as the 'digital economy' and 'digital innovation' – is already evident from the representation of the priority areas together with the expected impact areas.

Figure 28: Investment and impact overview

Source: DST/CSIR (2013: 20)

	INVESTMENT		IMPACT		
	Total to Exit ZAR M	Next Stage ZAR M	Contribution to economy pa ZAR Bn	New Businesses created	Job Creation
Broadband infrastructure and Services	800	419	12 Bn+	5 medium 1200 micro-businesses/operators	825 high-tech 2625+ other
Development	596	311	21Bn	3 medium 1000 micro-franchises	1750 other
Sustainability and the Environment	1,479	503	27.6 Bn	10 medium 55 small	1200 high-tech 6100 other
Grand Science	1,016	588	6.7 Bn+	1 large 4 medium 5 small	450 high-tech 1800 tech
Industry Applications	3,394	1,432	52.2 Bn	15 medium 130 small	1750 high-tech 7200 other
The Service Economy	2,101	1,411	Significant but direct	Significant but direct	Significant but direct
TOTAL	**9,385**	**4,664**	**120Bn+**	**1 large 37 medium 190 small 2200 micro**	**4,225 high-tech 19,475 other**

[133] DACST. 1999. *All our Futures*. Pretoria: Department of Arts, Culture, Science and Technology.

The Roadmap makes specific reference to the National Development Plan, which "sees ICT by 2030 underpinning a dynamic, inclusive and prosperous information society and knowledge economy, in which a seamless information infrastructure will meet the needs of citizens, business and the public sector, providing access to a wide range of services required for effective economic and social participation at a cost and quality at least equal to South Africa's competitors" (DST/CSIR, 2013).

The current discourse abounds with new terms: 'transformative technology', 'digital transformation', 'digital economy', 'digital innovation', 'gig economy' and 'the 4th industrial revolution'. An influential report by the OECD discusses the ways in which the digital economy will impact on the way we work.[134] The focus in this and similar reports is often on the three big transformative technologies: artificial intelligence, the internet of things, and block chain. These transformative technologies present some common features, notably their dependence on large data sets and a range of digital technologies, hence the current interest in big data and data science.

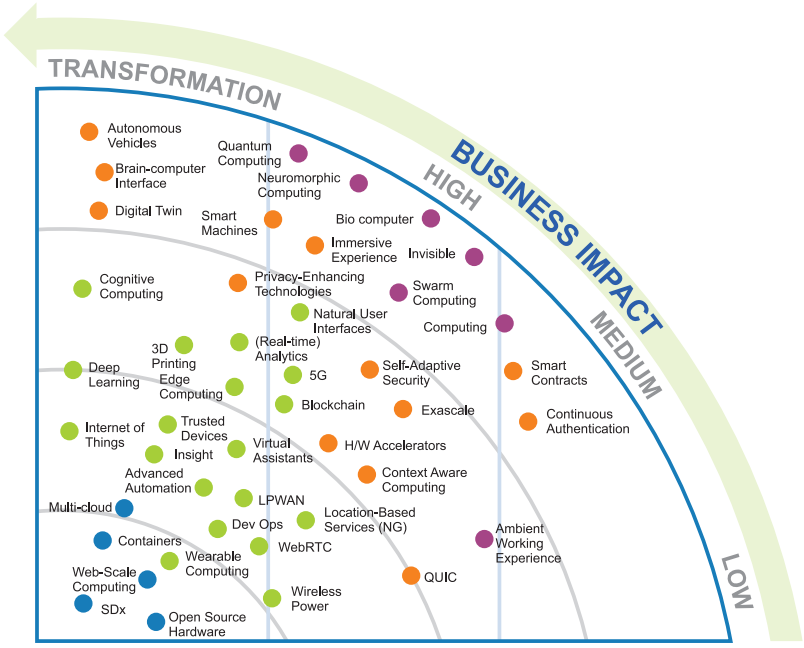
In a recent report, Atos[135] identified three digital megatrends that they claim will profoundly change our societies and business in the future:

- *The whole world becomes the computer,* surrounding customers and employees with immersive user experiences. From wearables to smart cars, smart homes, smart shops or smart factories, digital is pairing with and invading the physical world.
- *Intelligence takes control of the machines*, with AI rapidly rising to manage and derive value from the exponentially growing flows of data. This will dramatically augment human and business capabilities.
- *Infrastructure becomes a commodity* as it can easily be shared or outsourced, anytime, anywhere, 'as-a-service', in a centralized or peer-to-peer way. Whichever the industry, from data up to applications and services, everything goes into the Cloud.

In the same report, Atos presents the following 'radar' diagram that illustrates the wide range of business impact that these digital technologies have had over the past four years.

[134] OECD. 2018. *Transformative Technologies and Jobs of the Future. Paris:* Organisation for Economic Cooperation and Development. Available at: https://www.oecd.org/innovation/transformative-technologies-and-jobs-of-the-future.pdf.
[135] Atos. 2020. *Building the Intelligent Business Platforms of Tomorrow*. Available at: https://atos.net/content/mini-sites/look-out-2020/tech-trends/.

Figure 29: Business impact of digital technologies



Time of Impact

2018 Look today at how solutions could address your needs.

2019 Consider potential solutions by running pilots, for example.

2020 Understand now. consider potential implications and how these could be addressed in your strategic technology planning.

2021+ Follow for now. Watch how it's evolving.

Business Impact

Transformational Likely to require radical changes within organizations.

High Will have a high impact at work and in people's home lives.

Medium Will impact organizations' processes & services or affect users'& consumers' lives.

Low Will impact specific processes & services or affect some aspects of users'& consumers' lives.

Maturity

Mainstream There's a clear need and many clients are implementing solutions.

Early adopter Clients are starting to look for solutions.

Adolescent Discussed more widely by analysts and through leaders.

Emerging Mainly seen in academia and a small number of specialized markets.

The 2019 White Paper recognises the critical importance of the all-pervasive and ubiquitous nature of ICT as a transformative technology, and hence proposes that a policy nexus must be established to address, among others, the following priorities (DST, 2019: 56):

- Drive the digital society in South Africa
- Use big data at local government level to create jobs
- Use open data to transform local government services
- Create localised ICT hubs as Centres of Excellence
- Modernise local government services
- Use e-government services to transform local government services
- Prioritise cybersecurity resilience
- Support emerging start-up digital enterprises, and
- Address the high cost of broadband in South Africa.

The White Paper also acknowledges that giving expression to achieving these aims will require huge investment in the development of digital skills throughout the education sector. It also refers indirectly to the critical role that universities must play in developing high level knowledge and skills in new programmes in computer and data science. The White Paper specifically suggests that new research fields will develop around data mining, machine learning, privacy and database interoperability to enable big data science. We return to these issues in our recommendations below.

7.1.3 Nanotechnology

An explicit strategy for nanotechnology – *the National Nanotechnology Strategy* – was only published in 2006. Prior to the release of this strategy, several reviews had been done of the state of nanotechnology research and use in the country. These studies showed that nanotechnology activities were clustered predominantly at universities (mainly at previously advantaged institutions with a few historically black universities involved) and a few industries.[136] These studies found that nanotechnology-related research was focused mainly at the basic research level, with limited industry involvement other than a few large companies, which tended to contract their nanotechnology work to universities.

Under the heading 'Mechanisms for integrating nanotechnology with other strategies and initiatives', the DST's 2008 *Nanoscience and Nanotechnology 10-Year Research Plan* noted (DST, 2008: 8): "Because of its multidisciplinary nature, nanotechnology is a stand-alone platform technology with the potential to revolutionise many research applications and industries. However, within the context of integrating nanotechnology with other national strategic initiatives, it can also be viewed as a cross-cutting technology platform."

The overall assessment of our review (Volume 5: Annexure 16) showed that much has been done to boost nanotechnology research in the country, with nanotechnology outputs showing a marked increase and activities spread across institutions. Human capital development similarly can be seen with an increase in student graduations and in jobs for nanotechnology workers, with some transformation having occurred. However, the review also identified the lack of commercialisation of nanotechnology. Nanoscience as a field has become entrenched in the South African academic landscape, but does not appear to be yielding the full extent of the commercialisable outcomes required of the strategy. Various explanations have been put forward to explain the demonstrated 'slowness' in the development and commercialisation of nanotechnology in the country. For instance, insufficient time has elapsed since the introduction of the strategy for its full effect to be realised; and relatively little has been spent on nanotechnology in the country to date, meaning that it has not been sufficiently supported in order to reach its commercialisation possibilities.[137] Maruping[138] supports this assessment by outlining that there is an insufficient understanding in the South African environment as to what commercialisation is, and that it takes much more time and funding to take something to the market than is currently understood. Furthermore, she outlines that there are insufficient sources of funding to support businesses for the long timespan that is required until commercialisation is achieved. This is matched by an impatience from government, which does not create a supportive environment for commercialisation. These concerns are taken up in the recommendations below.

7.2 Recommendations

Recommendation:
We recommend that the DSI (and partners) undertake a fundamental re-assessment of the current technology programmes

The original objectives of the technology-related strategies in the NRDS and TYIP – to contribute towards the transition to a knowledge-based economy, to improve the sector's competitiveness through advanced manufacturing and innovation, and to leverage resource-based industries – are still valid. What has changed over time is the introduction of new initiatives such as in fluoride-based electrolytes, titanium powder, additive manufacturing and advanced materials. Technology changes are fast-moving and are often linked to new challenges resulting from fundamental shifts in social dynamics. We hence believe that it is prudent for the DSI to revisit its current portfolio of technology programmes (in the light of recent global developments as well as the recommendations of the Research Foresight exercise) going forward.

[136] Scriba M. 2004. Baseline Study on the Status of Nanotechnology R&D in South Africa (June/July 2004). Report for the Department of Science and Technology; Van der Merwe DL. 2004. Study of the South African Nanotechnology System. Master of Technology Management thesis, University of Pretoria.

[137] Lewis Y, Cohen B, Burke M, Harris A, Coetzee K & Logan A. 2018. Nanotechnology RD&I at Academic Institutions and Science Councils. Final Report. A report for the Department of Science and Technology.

[138] P. Maruping, interviewed by Margaret Ward, 26 June 2019.

Recommendation:
Digital skills and knowledge development

We recommend that the DST cyber infrastructure project be enhanced in four important ways: (1) a programme of R&D investment in universities and SET institutions that addresses the wider digital innovation agenda, focused on advancing new digital technology fields (such as artificial intelligence and social data analytics), as well as on digital applications in public education (e.g. digital applications in mathematics and science teaching), public health, digital government and nanotechnology to name a few; (2) a programme of investment in skills for digital R&D and innovation; (3) explicit attention to the gender, youth and other social dimensions of R&D and innovation for the digital economy/society; and (4) encouraging the design and use of applications of dynamic software in mathematics, science and technology subjects in primary and secondary schools. The DSI (and relevant departments) should foster and invest in large-scale research networks for digital innovation that draw in the universities, science institutions, private sector, public sector, and proto-innovation entities such as technology hubs, makerspaces and other digital innovation contributors, ensuring that these networks include geographic areas with low R&D funding. In this effort, attention must be given to investments that promote women in science, and science for women, in the digital innovation sphere.

Recommendation:
Nanotechnology: Strengthening areas of research, development and innovation

It is recommended that the current NIC programme be continued, but in a modified format, with an extended focus on research translation and commercialisation. It is also recommended that a review be commissioned to investigate the feasibility of continuing with two separate NICs (at the Council for Scientific and Industrial Research and Mintek). Such a review should address the question of whether better oversight and coordination of the national research agenda can be achieved; for example, through the development of a new roadmap of research priorities and opportunities to avoid duplication, enhance collaboration, and act as a focal point for the development of the skills required to optimise achievement of commercial outcomes. In addition, there are areas of relevance and potential impact not being addressed across the existing NICs, such as energy generation and storage, and food and health (e.g. therapeutics, treatment), although many of these are being addressed at other institutions across the country. A technology roadmap which provides granular detail is required to ensure research at every relevant institution is being directed appropriately. This applies equally to the commercialisation of research outputs, and could be achieved through high level direction from government through the alignment with new societal challenges.

CHAPTER

8

THE GRAND CHALLENGES

8.1 Introduction: On the genesis of the notion of a grand challenge

The notion of a 'grand challenge' appears in the TYIP in 2008. The stated purpose of introducing these grand challenges was that they would "address an array of social, economic, political, scientific, and technological benefits" and were "designed to stimulate multidisciplinary thinking and to challenge our country's researchers to answer existing questions, create new disciplines and develop new technologies" (DST, 2008: viii). Each of the grand challenges is outlined in a narrative, the details and scope of which vary quite widely, but in each case a set of "outcomes" plus some indicators were stated. The grand challenge areas are (ibid: 19):

- The Farmer to Pharma value chain to strengthen the bio-economy,
- Space science and technology,
- Energy security,
- Global-change science with a focus on climate change, and
- Human and social dynamics.

At the time of the drafting of the TYIP, the notion of a 'grand challenge' was already widely discussed and used in STI policy circles in North America and the EU. In a recent article, Tim Flink and David Kaldewey[139] discuss the origins and development of the concept of a 'grand challenge'. They compare and contrast the grand challenges concept with the concept of 'frontier research', which also became prominent in EU science and innovation policies in the early 2000s. According to Flink and Kaldewey, the grand challenges concept is not a research category in the narrow sense (Flink & Kaldewey, 2018: 17):

> *Rather, the concept is embedded in a discourse about the role and future mission of the scientific community. Most definitions conceive of grand challenges as long-term and largescale research goals, determined by heterogeneous societal stakeholders. Thus, communicating grand challenges is a way to talk about the goals and ends of scientific research. Ideally, this means democratizing priority-setting to make science more independent of economic interests.*

These authors point out that while many scholars consider the grand challenges discourse as a reformulation of mission-oriented research policy, others more carefully ask whether grand challenges are more

[139] Flink, Tim and Kaldewey, David (2018) The new production of legitimacy: STI policy discourses beyond the contract metaphor. Research Policy 47: 14 – 22.

than 'old wine in new bottles'. They show that whereas in the 1980s and 1990s the term grand challenges was nearly exclusively used in the fields of computational sciences and artificial intelligence, it was increasingly applied to other fields after the millennium, not least to mainstream disciplines such as physics and biology.

Flink and Kaldewey furthermore point out that within this paradigm a host of debates ensued: around the distinction between basic and applied research, the notions of excellence in research, and more recently the interest in translational research. Interestingly enough, all of these debates took the liner model of innovation for granted. This in turn led to a range of critiques of the underlying linear model. New models and terminology abounded: 'post-normal science',[140] 'mode 2',[141] and the 'triple helix' model.[142] Flink and Kaldewey (2018: 15) argue that none of the academically inspired concepts and distinctions found much traction in government policy deliberations – mostly because they did not resonate with the everyday language and practices of policy analysts on the ground: "As a consequence, those concepts have not resulted in STI policy discourses as influential and commonsensical as the allegedly outdated models of technology transfer and linear innovation."

But this trend would change with the establishment of the European Research Council in 2007 and the inclusion of the notion of 'frontier research' in its Framework Programme 7. The idea that research and innovation should address major societal challenges, generally with the added epithets 'grand' and/or 'global', was officially introduced in the so-called "rationale report" in 2008 (EUC, 2008),[143] and soon became incorporated in official EU policy discourse through, in particular, the Lund declaration (July 2009). It has since been implemented in emergent EU research and innovation policies; in particular, as one of three main pillars of the Horizon 2020 programme. Other influential international organisations promote similar notions about addressing global challenges through research and innovation. The 2010 *OECD Innovation Strategy* included a chapter on applying innovation to global and societal challenges. The Royal Society has added its voice to calls for improving and scaling up international cooperation in STI to address global challenges. The notion of a 'grand challenge' is also part of official US research and innovation policy where harnessing S&T to address the "grand challenges" of the 21st century was one of the goals of President Obama's 2009 Strategy for American Innovation. This list can be expanded to include other organisations, regions and nations, where the (grand) challenges notion has come into common use in the way overall policy goals and rationales for supporting and mobilising research and innovation are being framed.

The EU's Horizon 2020 framework programme introduced yet another semantic innovation: the 'societal challenges' rationale (European Commission, 2011a, 2011b).[144, 145] According to the Commission, this reflects a changing of "policy priorities" to address "major concerns shared by citizens in Europe and elsewhere" (European Commission, 2011a: 5). According to Flink and Kaldewey, the aim of Horizon 2020 was to achieve these major concerns with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal was to ensure that Europe produced world-class science, removed barriers to innovation, and made it easier for the public and private sectors to work together in delivering innovation.

Horizon 2020 was based on a challenge-based approach which brings together resources and knowledge across different fields, technologies and disciplines, including the social sciences and humanities. This covers activities from research to market with a new focus on innovation-related activities, such as piloting, demonstration, test-beds, and support for public procurement and market uptake. Funding focused on the following challenges:

- Health, demographic change and wellbeing;
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the bio-economy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;

[140] Funtowicz S & Ravetz J. 1993. Science for the post-normal age. Futures, 31(7): 735-755.
[141] Gibbons M. et al. 1994. The New Production of Knowledge: The dynamics of science and research in contemporary societies. California: Sage Publications.
[142] Etzkowitz H & Leydesdorff L. 2000. The dynamics of innovation: From national systems and 'Mode 2' to a triple helix of university–industry–government relations. Research Policy, 29(2): 109–123.
[143] European Union Commission. 2008. Challenging Europe's Research. Rationales for the European Research Area (ERA). Report of the ERA Expert Group, EUR 23326 EN200. Office for Official Publications of the European Communities, Luxembourg.
[144] European Commission. 2011a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Horizon 2020–The Framework Programme for Research and Innovation. Brussels: European Commission.
[145] European Commission. 2011b. Proposal for a Regulation of the European Parliament and of the Council establishing Horizon 2020–The Framework Programme for Research and Innovation. Brussels: European Commission.

- Climate action, environment, resource efficiency and raw materials;
- Europe in a changing world – inclusive, innovative and reflective societies; and
- Secure societies – protecting freedom and security of Europe and its citizens.

Even a cursory inspection of the five grand challenges as outlined in the TYIP shows that most of them do **not** correspond with the notion of a 'grand societal challenge' as outlined in the more recent OECD documents and strategies referred to above. The seven societal challenges listed above all refer very specifically to problems and deficiencies that are present and grounded in society: in health care (including the burden of disease), food security (such as hunger and malnutrition), safe and clean energy, the problems of pollution and high carbon-emissions, problems related to refugees and migration, lack of social cohesion, poverty, inequality and so on. These are not **scientific** or **technological** problems – they are simply **human** problems. What is distinctive about the OECD approach since 2008 is that the societal challenges (or set of complex problems) are taken as the starting point from where an S&T policy and strategy needs to be developed. Whereas in traditional S&T missions strategies were developed from the perspective of the science base or technological capabilities, 'directionality' in current STI policies has its origins in society and our diagnosis of key societal challenges.

8.2 The TYIP grand challenges

Despite being grouped together under the rubric of 'grand challenges', the individual grand challenges in the TYIP are in fact not very similar. Close inspection shows rather big differences in the underlying premises and logic. In a nutshell, we will argue the following:

- That the grand challenges of 'global change' and 'energy security' – and to a lesser extent 'bio-economy' – correspond to current notions of societal challenges.
- That the 'space science and technology' grand challenge is better understood as an expanded science and technology mission.
- That the thinking behind the 'human and social dynamics' grand challenge was flawed from the outset, and conflated a substantive focus (on social issues) with the ideal of giving expression to the transversal nature of social, economic, legal and ethical dimensions in most science and technological interventions.

8.2.1 How the TYIP grand challenges correspond with current notions of 'societal challenges'

The terms 'energy security' and 'global change' (read 'climate change') evidently refer to two of the most urgent societal problems of our times. It is therefore not surprising that these challenges are included in many science and innovation policies, including the 2019 White Paper.

In his review of the TYIP's **energy-security** grand challenge, Walwyn (this review, Volume 5: Annexure 19) concluded that:

- The energy-related objectives of the TYIP were not clearly organised. Thus, for example, strategic objective 1 relates to the need for energy security and the associated interventions relate to non-renewable-based energy generation. Strategic objective 2 also relates to the need for energy security and the interventions centre on renewable energy generation.
- The DST's implementation of the energy grand challenge focussed on supporting research and technology development in six main areas: The Advanced Biofuels Programme; Hydrogen South Africa; Renewable Energy Hub and Spoke; Energy Efficiency; Energy Storage; and Carbon Capture and Use.
- A confusion of mandates between the DST, the Department of Energy and the Department of Public Enterprises resulted in sub-optimal achievement of the overall objectives of the grand challenge.

However, it acknowledged that much of the decline in energy management over the past decade or more cannot be assigned to the DST. However, implementation of the energy grand challenge has formed a core part of the DST's activities since the adoption of the TYIP. Funding for the initiative, which was primarily a research activity, has on average accounted for about 20% of the total energy supply-related R&D, and

amounted to a total of about R1.319 billion since the adoption of the TYIP. The DST, therefore, should take responsibility for at least part of the failures.

Notwithstanding this initial comment, there are a number of aspects which have worked and from which some general principles can be extracted. The decision to establish three centres of competence within the higher education sector was far-sighted. At the time, the benefits of this arrangement may not have been apparent and in this sense, the arrangement can be considered as an example of policy experimentation. The two clear benefits are that by using the universities as places of technology development, the DST allowed the simultaneous development of human resources and new knowledge (for the hydrogen economy). The challenge, and this aspect is what the DST is currently tackling, is the limitations of the university environment as a platform for industry development or close-to-market product development. The approach being followed by the DST is to actively engage with small firms which are able to provide this platform on a cost-effective basis.

In the final analysis, 'energy security' remains a key societal challenge (even more so today) that needs to remain on our STI agenda. The fact that many of the original objectives of the 2008 grand challenge have not been met (not least because of the capture of Eskom and the devastating effects of its mismanagement on energy security in the country), does not invalidate its strategic importance for the economy and society.

The 'evolution' of the **bio-economy** grand challenge over time shows how its genesis can be traced to the 2001 National Biotechnology Strategy, which 12 years later changed fundamentally with the publication of the Bio-economy Strategy in 2013. It is clearly an example where the design of the grand challenge in 2008 stands in the extension of a technology-push approach. The 'remnants' of this technology-driven approach are still found in the detail of the objectives. But it is interesting that the three high-level strategic objectives (related to agriculture, health, and industry and the environment) refer directly to societal challenges. Thus, for instance, the strategic objective relating to agriculture is to "strengthen agricultural biosciences innovation to ensure *food security*, *enhance nutrition* and *improve health*", while the strategic objective with regard to health is to "support and strengthen the country's local research, development and innovation capabilities to manufacture active pharmaceutical ingredients, vaccines, biopharmaceuticals, diagnostics and medical devices to address the disease burden while ensuring security of supply of essential therapeutics and prophylactics" (see Volume 5: Annexure 17).

In an approach where the societal challenge is taken as point of departure, these end-states (food security, good nutrition, improved health, and reduced burden of disease) would define the grand challenge (again as evident in the EU's list of societal challenges).

- It is worth noting that there are overlaps and interconnections between some of the grand challenges. The grand challenge on **global change** is clearly focused on climate change. Having said this, the breakdown into four cross-cutting research challenges and 18 research themes in DST's 2010 *10-Year Global Change Research Plan for South Africa* (see Figure 30 below) also indicates some clear overlaps with the bio-economy and energy security grand challenges. Themes related to food security also appear in the Bio-economy Strategy as do references to sustainability and the greening of the economy which are also found in the energy security grand challenge.

Figure 30: Knowledge challenges and research themes for the Global Change Research Plan

Understanding a changing planet	Reducing the human footprint	Adapting the way we live	Innovation for sustainability
• Observation and monitoring • Dynamics of the oceans around Southern Africa • Dynamics of the complex internal earth system • Linking the land, air and sea • Improving model predictions at different scales	• Waste-minimisation methods and technologies • Conserving biodiversity and ecosystem services • Institutional integration to manage ecosystems and ecosystem services • Doing more with less	• Preparing for rapid change and extreme events • Planning for sustainable urban development in a South African context • Water security for South Africa • Food and fibre security for South Africa	• Dynamics of transition at different scales – mechanisms of innovation and learning • Resilience and capability • Options for greening the developmental state • Technological innovation for sustainable social-ecological systems • Social Learning for sustainability, adaptation, innovation and resilience

The overlaps across the grand challenges are not unexpected: both because of the integrated nature of societal problems (which makes a disentanglement into discrete interventions difficult), as well as the fact that complex interventions such as these invariably morph over time and goal-drift results.

8.2.2 The space science and technology grand challenge

We would argue that the space science and technology grand challenge does not constitute a societal challenge as the term is currently used. The thematic areas and the subsidiary interventions relating to this grand challenge (listed below) are predominantly aimed at scientific and technological advancements and developments as well as the building and strengthening of appropriate infrastructure:

- **Earth Observation**
  - ✓ Establish an earth observation data centre
  - ✓ Develop a platform to integrate satellite and in-situ data
  - ✓ Develop medium to high resolution payloads
  - ✓ Establish centres of competence for optronics and synthetic aperture radar
  - ✓ Develop the African Resource and Environmental Management Constellation in partnership with other African countries
  - ✓ Consolidate the acquisition of space data for government
- **Satellite Communications**
  - ✓ Develop technologies for low data rate payloads
  - ✓ Develop technologies for applications in e-education, telemedicine and rural communication and disaster support
  - ✓ Develop a geostationary (GEO) communications system
  - ✓ Launch a small GEO satellite
- **Navigation and Positioning**
  - ✓ Develop a navigation augmentation system
  - ✓ Develop navigation applications to support user requirements
- **Space Exploration**
  - ✓ Grow the knowledge economy through space environment research, and applications development
  - ✓ Develop joint partnerships in space science payloads

- ✓ Establish and support centres of competence
- ✓ Establish and support research chairs

This is not to deny the potential value of various space and satellite applications related to grand challenges in climate change and food security. But the reality is that these goals and objectives are much more akin to those of a science, technology and infrastructure mission than those of a grand challenge. It is also worth pointing out that our review found that the South African National Space Agency remains seriously under-funded, which impacts on its ability to achieve even some of the objectives as listed above (see Volume 5: Annexure 18).

8.2.3 The human and social dynamics grand challenge

In retrospect, it is clear that the HSD grand challenge was never properly conceptualised and designed as a grand (societal) challenge. On the one hand, the authors attempted to include some substantive social issues on the agenda of the grand challenge (references made to improving education and skills to reduce crime; from curbing the spread of HIV/AIDS to developing a sustainable approach to energy; and from reducing xenophobia to building more inclusive communities). On the other hand, many of the specific objectives and subsequent interventions focused on the cross-cutting and 'meta' functions that the social sciences and humanities perform vis-à-vis other scientific domains. In addition, other seemingly unrelated topics such as strengthening policy-advice and uptake, research dissemination and science engagement were grouped together under this heading.

According to spokespeople from the DSI, the HSD grand challenge – in more recent times – "has two focal points: the humanities and social sciences (HSS), and Innovation for Inclusive Development (IID). The objective of the HSS portfolio is to support the generation, application and dissemination of humanistic and social scientific knowledge. The objective of the IID portfolio is to accelerate inclusive development through scientific knowledge, evidence and appropriate technology." Furthermore, because of continued underfunding, the DST decided in to cease funding for the programme: "for strategic reasons, the research and innovation underpinnings of the HSDD GC is captured and reflected in the new STI White Paper. As such, the HSDD GC as a policy and strategic driver is now defunct given the fact that the policy intents of the new WP underscores the importance of the HSS and IID in the NSI."

If we compare how the HSD grand challenge was conceptualised with the current list of Horizon 2020 and SDG goals, it is clear that not sufficient thought went into what social and developmental challenges (such as crime, mental health, stress, poverty, inequality, poor schooling and teacher training, social cohesion, unemployment, etc.) could have been included into the strategy. It is clear that the authors of the original document confused different levels or domains of social analysis and how the humanities and social sciences contribute to these:

- A focus on substantive challenges in society through a focus on social issues (such as those listed above);
- The contribution of the social sciences and humanities in terms of the traditional ELSI (ethical, legal and social implications) and ELSA (ethical, legal and social aspects) of science and emerging technologies frameworks; and
- The meta-level contributions of fields such as the sociology of science and STI policy to issues regarding the production and dissemination of research, the nature of science communication and science engagement, and studies on policy-making and learning in STI.

8.3 Towards grand societal challenges

We began this chapter with a brief outline of the origin and emergence of the notion of grand challenges and, more recently, societal challenges. According to Chicot and Matt,[146] much of the literature on STI policy compares two different kinds of challenge-oriented policies: historical mission-oriented programmes such as the Manhattan and Apollo projects, and challenge-driven STI policy focusing on societal challenges (climate change, ageing population, and public health). The first type of policy provides solutions to well-defined problems, framed in technical terms and requiring the development of specific technological capabilities. These policies are based on a top-down, rational planning approach. They support the competitiveness of specific industries (defence, aerospace) through the choice of a well-defined direction in order that the solutions satisfy a clear end goal.

[146] Chicot J & Matt M. 2018. Public procurement of innovation: A review of rationales, designs, and contributions to grand challenges. *Science and Public Policy,* 45(4): 480–492.

In contrast, the societal challenges underpinning grand challenges are complex, multisided, uncertain, unstructured, and difficult to manage, and comprise problems that call for long-term transformative change.[147] Such fundamental change requires transformation of the whole system of innovation production and consumption; that is, new configurations of actors and knowledge bases, cross-sectoral collaboration, technological and social innovations, a wider set of institutions and interests, multilevel policy efforts, and multiagency responses related to the long run.

'Grand challenges' related, for instance, to environmental and health issues, have become increasingly pervasive in both policy discourse and in the STI policy literature. Grand challenges call for system wide transformations where a single instrument is insufficient. They require policy-makers to implement policy mixes[148] that include demand-oriented policy measures, and public procurement of innovation has generally been considered a suitable instrument.

There is a consensus that grand challenges require more than current innovation policies justified by 'traditional' rationales such as market and structural system failures, and that what is needed is a system transformation.[149] According to Weber and Rohracher, policy interventions addressing grand challenges need to consider transformational failures; that is, directionality, demand articulation, policy coordination, and reflexivity failures in addition to market and structural system failures.

In their analysis of a large number of OECD and related policy documents, which make reference to grand or global challenges, Kallerud et al.[150] developed an analytical framework according to which such strategies contain or correspond to 12 dimensions. The table below is a summary of their analytical framework.

Table 8: Core dimensions of grand (societal) challenges

Dimension	Elaboration
Framing (rhetoric)	The concept of a grand challenge as a rhetorical device to justify the commitment and value that research makes to public and private sector in addressing economic, social and environmental goals.
Scales of stakes	The notion of a 'grand' challenge conjures up images of 'life and death' choices, the need to address the 'survival' of firms and national economies and significant 'threats to societies and ecosystems'.
Grand or global?	The terms 'grand' and 'global' have been used interchangeably. While the notion of 'grand challenges' has become ubiquitous in European R&I policy, other players (the OECD, Royal Society) prefer the 'global' term, which more explicitly links this approach to processes and issues of 'globalisation', both in terms of stakes, thematic focus and interactional requirements (international cooperation). But there is often a quick 'slippage' from grand to global as in the following statement in the EU Innovation Union: "many if not all of the societal challenges on which Europe's research and innovation efforts must focus are also global. Overcoming many of these challenges calls for worldwide sharing of efforts. In particular, many major research infrastructures require massive investments that can only be raised through global cooperation."
Scale or effort	For such challenges to be addressed effectively, more intellectual and monetary resources are required than what single actors, even large nations, alone can muster. A shift towards a challenges approach implies that few efforts and programmes should be considerably up-scaled so as to reflect the much higher stakes involved in those particular cases than for any 'normal' mission-oriented R&I effort.
Thematic variety and centrality	While climate change, global warming and clean energy are issues that are always listed as grand and global challenges, it varies much more between contexts both with regard to which other topics qualify as grand/global challenges and how they are framed as challenges at those levels of stakes and efforts.

[147] Weber M & Rohracher H. 2012. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. *Research Policy*, 41: 1037– 1047.

[148] Kuhlman S & Rip A. 2014. *The Challenge of Addressing Grand Challenges: A think piece of how innovation can be driven towards the 'grand challenges' as defined under the prospective European Union Framework Programme Horizon 2020.* European Research and Innovation Area Board. Available at: https://ec.europa.eu/research/innovation-union/pdf/expertgroups/ the_challenge_of_addressing_Grand_Challenges.pdf.

[149] Mazzucato M. 2016. From Market fixing to market-creating: A new framework for innovation policy. *Industry and Innovation,* 23(2): 140–56.

[150] Kallerud et al. 2013. *Dimensions of research and innovation policies to address grand and global challenges.* Working Paper 13/2013. Available at: https://pdfs.semanticscholar.org/1032/2815675aa3e488522f7277fc9551e7fc25d6.pdf.

Dimension	Elaboration
Temporal scope	On the one hand, it is 'urgent' to find solutions to pressing major challenges (as in the OECD STIG report). On the other hand, an open, long-term effort is required to produce the new scientific knowledge and the truly new and innovative technologies that may open up new venues for effective solutions. Hence, at least in some versions, the role of basic research is strong.
Multi-objective policy	Often the challenge approach is introduced and developed as concerned with 'social/societal' and/or 'public' issues, in contrast to approaches developed within the economic policy domain. The latter are focused on economic objectives; in particular, economic growth, and primarily targeting 'private' actors (i.e. private firms, their framework conditions and primary field of operation [markets]). It is thus argued that it is "artificial to separate economic, social and environmental opportunities since they all involve business, government and other stakeholders."
Orientation and steering	A key difference between policies to address challenges and policies to sustain (overall) economic growth is that the former involves some degree and form of steering of efforts towards a specific mission or objective. Similarly, the accompanying "rationale for action" document to the EU Innovation Union communication states that the overall orientation of challenge-oriented and supply-oriented R&I policies differ by the fact that addressing challenges "involves placing a far greater emphasis than hitherto on attempts to influence the direction rather than the rate of technical change and innovation."
Interactional mode (collaboration vs. competition)	One dimension along which R&I policies to address challenges may differ from R&I policies to sustain economic growth and the competiveness of firms and national economies is their different emphasis on collaboration and competition respectively. For example, there may be a stronger emphasis in challenge-oriented policies to develop policies and deploy resources within formal collaborative frameworks (organisations, programmes) at the supra-national level, while in a national framework for developing R&I policies concerns with the competitiveness of the national economy will be strong. Schematically, while competition may be deployed in the service of collaboration in the grand challenge approach, defined by a search for common solutions through international collaboration, the reverse may be the case in policies for growth and competitiveness within national (and regional) frameworks to support the interests and capability of the 'own' actors (economy, firms, researchers).
STI spectrum	One important dimension along which policy initiatives to address some or other grand and global challenge may differ widely from each other is the relative 'location(s)' of actions along the STI spectrum – from basic, oriented/strategic and applied research over development on demonstration to innovation commercialisation or effective resolution of the challenge in question. While schemes for collaboration in research are well developed, few collaborative models exist at the 'innovation' part of the spectrum (except within contexts of development, aid and philanthropy), where concerns of commercialisation, market return, competition and protection of intellectual property often prevail. The strong emphasis on 'resolving' challenges may indicate that efforts at the innovation end of the spectrum may be mandatory in any 'complete' challenge-oriented policy, as neither new knowledge nor new technologies can in themselves be expected to resolve any major issue/challenge.

Dimension	Elaboration
Stakeholder involvement	While the political authority and the privileged access to resources of governments and national and international agencies and organisations put them in key positions in the organisation, funding and implementation of challenge-oriented initiatives, addressing challenges through R&I is nowhere seen to be appropriately organised through top-down steering and hierarchical organisations structures. While the notion of 'partnerships' is also becoming common as a venue for addressing grand and global challenges, these partnerships are conceived as having to be particularly extensive, inclusive and heterogeneous (in contrast to, for example, the triple helix structure of partnerships for 'the knowledge-based economy'). Statements along the line of the following abound: "Nevertheless, some common strategies are emerging: greater involvement of the private sector, non-governmental organisations, philanthropic organisations, and other stakeholders in the prioritisation and delivery of science and innovation." It is an issue of "empowering new players": "Non-governmental organisations, private, often philanthropic, foundations and social entrepreneurs which often are driven by non-profit motives can play an important role in catalysing innovation to solve social problems that are insufficiently addressed by governments or the market."
Governance	The assumption of collective, collaborative steering of socio-technical change found in transition management thinking accords well with the governance themes that are explicit and implicit in grand challenge discourses. Although there is diversity in these discourses, themes of integration, systems thinking and inclusive decision-making are typically evident. Transition management appeals to concepts of complex adaptive systems, social learning, co-evolution, adaptive capacity and self-organising networks, which involve varying degrees of societal involvement and cooperation.

Kallerrud et al. conclude (ibid: 2):

> *In another analysis, the "recent policy debates about research, technology and innovation towards societal challenges, rather than economic growth only" is seen to indicate the emergence of a new type of policy for "transformative change". Policies for transformative change do not only address "failures" as defined within systemic innovation policy frameworks, i.e., infrastructural, institutional, interactional and capability failures; one needs to add a new type of failure, viz. directional failures: policies for transformative change not only require that innovations be generated as efficiently and effectively as possible, but also that these innovations contribute to a particular direction of transformative change. This involves, inter alia, the identification of major societal problems or challenges for which solutions need to be developed with the help of research and innovation, the formation of collective priorities and the development of shared visions. This framing of the turn towards social challenges indicates a central role for such frameworks as transition management, multi-level governance and co-evolution of social, institutional and technological systems.*

In a recent paper, Mazzucato[151] advocates for combining the approach to grand societal challenges with new mission-oriented innovation policies. But she is at pains to point out that her use of the term 'mission-oriented' policy is very different from traditional science and technology missions. She contrasts the new with the old use of the term, as outlined in the figure below (Mazzucato, 2018).

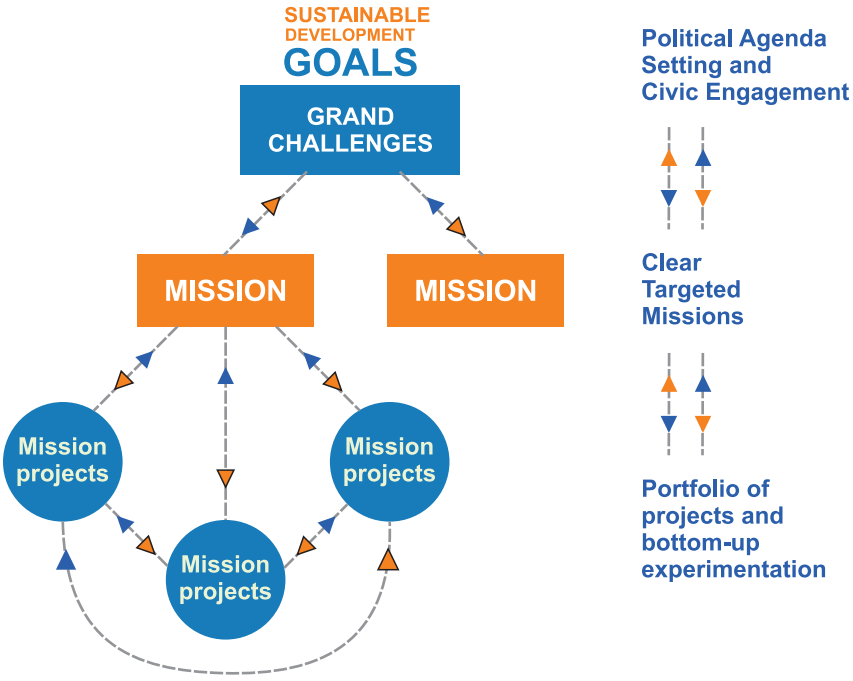
[151] Mazzucato M. 2018. Mission-oriented innovation policies: challenges and opportunities. *Industrial and Corporate Change*, 27(5): 803–815.

Table 9: Contrasting old and new mission-oriented projects

Defense, nuclear and aerospace	New: Environmental technologies and societal challenges
Diffusion of the results outside of the core of participants is of minor importance or actively discouraged The mission is defined in terms of the number or technical achievements, with little regard to their economic feasibility The goals and the direction of technological development are defined in advance by a small group of experts Centralized control within a government administration Participation is limited to a small group of firms due to the emphasis on a small number of radical technologies Self-contained projects with little need for complementary policies scant attention paid to coherence	Diffusion of the results is a central goal and is actively encouraged The mission is defined in terms of economically feasible technical solutions to particular societal problems The direction of technical change is influenced by a wide range of actors, including government private firms and consumer groups Decentralized control with a large number of agents involved Emphasis on the development of both radical and incremental innovations to permit a large number of firms to participate Complementary policies vital for success and close attention paid to coherence with other goals

For Mazzucato, missions should be broad enough to engage the public and attract cross-sectoral investment, and remain focused enough to involve industry and achieve measurable success. By setting the direction for a solution, missions do not specify how to achieve success. Rather, they stimulate the development of a range of different solutions to achieve the objective. As such, a mission can make a significant and concrete contribution to meeting SDGs or societal challenges. She illustrates this approach as per the diagram below (ibid: 810).

Figure 31: The relationship between grand challenges, missions and mission projects



8.4 Recommendations

Recommendation:
The DSI should pursue the notion of 'grand societal challenges' as a framing principle for the development of the high-level interventions in the next decadal plan

We believe that recent scholarship in STI policy design has shown that such an approach is justified where countries (perhaps more so developing countries) are faced with complex, persistent and seemingly intractable societal problems. The caveat to this recommendation is that the conceptualisation and design of such grand challenges should adopt the learnings from recent reviews of similar instruments elsewhere. The current global (climate) change and energy security grand challenges should be included in the redesign of the societal challenges. The current bio-economy grand challenge should be reconceptualised with a focus on at least food security (a possible new grand challenge) and burden of disease (an essential addition to the grand challenges given current experiences with the coronavirus pandemic).

Recommendation:
An independent study should be undertaken on the current grand challenge for space science and technology

Such a study should look into the possibility of it being redesigned as an expanded (with sufficient funding) S&T mission as well as its possible integration with the astronomy/SKA/Meerkat mission.

CHAPTER 9

FINANCING OF RESEARCH AND INNOVATION

9.1 Reflections

The previous system-wide reviews recognised that the South African STI system is under-financed, that public expenditure on R&D is insufficient, and that the contribution of the business sector to R&D has declined to alarming proportions. In our recent report, *The State of the South African Research Enterprise*, we reaffirmed the findings of these reviews:

South Africa invests too little in R&D.

Although nominal expenditure has increased, GERD/GDP has remained unchanged at around 0.8% for most of the past fifteen years. This translates in a world rank of 44 on GERD/GDP in 2015. The national target, as expressed in many policy documents, of 1% remains elusive. South Africa's poor performance in research funding is best illustrated by the fact that, when compared to eight very similar research systems, our investment is less than half of their mean investment.

SA does not compare favourably with the rest of the world in funding of research

The value of GERD/GDP of 0.8% puts South Africa in 44th position in the world in 2015. The Lead countries on this indicator in 2015 spent around 5 to 4 times more on R&D than South Africa (Israel and South Korea at 4.2%; followed by Switzerland, Japan and Sweden at around 3.3%. Even when compared with our Comparator (most similar) countries, South Africa is second last behind Malaysia (1.3%), Portugal (1.24%), Poland (1.0%), Greece (0.97%) and Turkey (0.88%). SA is the lead country on the African continent where the average GERD/GDP in 2015 was around 0.3%.

Steady increase in GERD per capita but decline in comparative world rank

Expenditure per capita (in current $'000) has increased from 56$ in 2001 to 105$ in 2015. Despite this near doubling of GERD per capita, SA's rank on this indicator is even lower (56) than its rank on GERD/GDP. To understand why this is the case, one only needs to look at what the Lead countries in the world spent per capita on R&D in 2015: Switzerland ($2 100), Singapore ($1 854), Israel ($1 619), Sweden and the USA both around $1 550 followed by Austria ($ 1 500), South Korea and Denmark (both at $ 1 450). Even when compared to more similar sized-research systems, South Africa does not compare well. The top Comparator countries spent between 2 and 3 times more per capita on R&D than us.

Significant decline in the contribution of the business sector to expenditure on R&D in the country

Expenditure by source of funding shows that the government increasingly funds the biggest proportion of R&D in the country. Whereas the business sector (BERD) funded approximately 56% of all R&D in 2001, this proportion has declined to 39% in 2015. Over the same time period government's proportion of R&D increased from 36% in 2001 to 45% in 2015. Funding sourced from overseas sources doubled over the same period from 6% to 13%. While it is of concern that business is increasingly investing less in R&D in South Africa (proportionate to the other sectors), the decline must be seen in the context of South Africa's substantially larger GDP. And while business' proportion is declining, it still spent a substantial amount of R13.8-billion on R&D in 2015/16.

Decline in proportion of R&D devoted to experimental development

R&D by type of activity has also changed and most pertinently as far as the proportion of funding for experimental development is concerned. In 2001 32% of R&D was classified as involving experimental development. By 2015 this proportion had declined to 25%. This change is mainly due to the increased expenditure on applied research which increased from 40% in 2001 to 48% in 2015. Expenditure on basic research remained unchanged at around 25%.

The declining trend of BERD has been recognised by the South African government. The causes of this trend are also reasonably well understood, and include the partial demise of several large companies which were responsible for the bulk of BERD (e.g. Anglo American and Eskom), the movement of local R&D to other countries (De Beers and others), and the closure of the Pebble Bed Modular Reactor. The DST has adopted a broad set of instruments to deal with this problem, including the introduction of the R&D Tax Incentive, the establishment of the Technology Innovation Agency, and the direct funding of BERD in certain sectors such as energy, biotechnology and pharmaceuticals (Walwyn et al., 2016: 73).[152]

9.2 Recommendations from previous reviews and policy intents in the 2019 White Paper

A summary list of recommendations from previous reviews include the following:

- Recommendation: *A unitary Research and Innovation Vote … to function as a macro-coordinating mechanism to ensure that the country's public researchers in all public research-performing institutions … are adequately supported to inform their work. (2012 Ministerial review, p19)*
- Recommendation: *… a new, additional mode of public grant-making based on the principal of cooperatively allocated sectoral funds. … The new funds should be structured so that they constitute well-informed consultative forums, including industry and government actors, for the identification of sector-specific strategic priorities and the development of corresponding research and innovation agendas. (ibid.: 20)*
- Recommendation: *The research investment climate must be improved through a review of present and further possible incentive schemes for their accessibility, simplicity and effectiveness, with broadening as required. (ibid: 27). Measures listed include: THRIP, SPII, "specially tailored grants and concessions" required by SMES, regulatory environment for research and work permits, "sources of public capital support for innovation activities", diversified approach to government system of company support and incentivisation, and industry-public researcher linkages.*
- *… the NSI in South Africa is now generally in stasis, heavily stabilised and constrained within itself, and can be only be moved to a different state by investments aimed at the country becoming a knowledge economy. The means by which the system is resourced thus become critical levers for the steerage of the system, and for its general vitality. The biggest constraints are the stuttering pipeline of trained and knowledgeable people, at all levels; the inadequate investment in the research teams that do exist; not keeping up with infrastructure requirements; and failing to incentivise private investment in innovation, both within and from outside the country. Financing of the system must henceforth be driven in a new and more purposeful manner. (ibid: 43)*

[152] Walwyn D, Bertoldi A, Kaplan D, Maharajh R, Manzini S & Motala E. 2016. *Review of the White Paper on Science and Technology*. Pretoria: National Advisory Council on Innovation.

- Recommendation: *Public resourcing of R&D conducted at HEIs should be significantly increased. (ibid.)*
- Recommendation: *Business/industry should be encouraged and incentivised to increase its R&D expenditure. (ibid.)*
- Recommendation: *The incentive schemes offered by the dti and TIA/DST should be expanded. (ibid.)*
- *Establish a unified science vote. Alternatively, establish a new funding regime to promote a unified system of national innovation that will include universities and institutions performing R&D (i.e. provision of a unified science R&D budget). Furthermore, incentives must be created systemically to enhance institutional collaboration among South African universities, research institutions (including the science councils), regulators, and government departments. (DST, 2017: 113)*

Some of these recommendations have been adopted by the new White Paper, which lists four policy intents related to financing (DST, 2019: 63):

- Increase funding to the NSI, with a focus on increasing business and foreign investment in STI, as well as to
- Encourage provincial and local governments to invest more in STI as part of their development strategies.
- Improve the allocation of public funding for STI, and the coordination of public investment, to ensure that government's STI priorities are appropriately funded.
- Enhance the efficiency of funding in the NSI.

Given the dire situation of the economy and the real possibility that the first (and even the second) intent (to increase GERD/GDP to 1.5%) will not materialise, it is perhaps prudent to focus on strategies to improve coordination of current investments, as well as ways to enhance the efficiency of funding in the NSI. With regard to the latter, the following paragraph is illustrative of this thinking (ibid: 66):

> *To ensure that public STI funding is deployed productively, an STI investment framework will be institutionalised, under the auspices of the Ministerial STI Structure, to serve as a mechanism for prioritising and allocating funds. This will involve collaboration between the DST, National Treasury and the Department of Planning, Monitoring and Evaluation (DPME). Finally, to improve funding efficiencies, the mandates and funding instruments and incentives of institutions such as the Technology Innovation Agency (TIA), the National Intellectual Property Management Office (NIPMO), parts of the Industrial Development Corporation (IDC) and parts of the National Research Foundation (NRF) will be harmonised, and the administrative capabilities of the relevant institutions improved (e.g. through simplified application procedures, improved turnaround times and standardised evaluation approaches, where appropriate).*

Against this backdrop, our recommendations regarding financing are also skewed towards interventions that will produce greater coordination and efficiency gains.

9.3 Recommendations

Recommendation:
Institutionalise private sector cooperation and agreement when designing interventions to increase financing of innovation

For initiatives which involve significant private sector cooperation and agreement, prior consultation with private firms on the details of implementation is essential. We formulate this as a general recommendation specifically based on our review of the R&D Tax Incentive. Although there was some initial consultation, this was insufficient to counter the initial suspicion of, and resistance to, the scheme. Moreover, such initiatives must be accompanied by a significant public awareness campaign. In many cases, it appears that the target beneficiaries were unaware of the scheme, how it operates and how it could assist them.

Recommendation:
Continuance and strengthening of the R&D Tax Incentive scheme

Raising new revenue from National Treasury, or persuading it to give up existing tax revenue, will be almost impossible in the next five-to-ten years. The DSI should therefore take great care not to relinquish its tax incentive despite recent negative reviews, but work much harder to improve the impact of the scheme over the next period. Our review showed that although the scheme has not induced the necessary behavioural change in the private sector (increase in R&D expenditure), it has been implemented quite successfully from an administrative perspective, despite some initial teething problems. In particular, it is noted that the scheme was not shaped by a dedicated strategy; it relied heavily on the agreement of another government department; and it lacked, at least initially, a clear set of outcome measures. As a result, it took time to find a modus operandi which could meet the needs of all its participants.

Recommendation:
Undertake an in-depth review of existing funding instruments targeting business and innovation in order to achieve optimal coordination and efficiency

This recommendation is in line with the fourth policy intent around financing in the 2019 White Paper. It is also specifically informed by our review of TIA as well as an analysis of the different funding programmes at DSI and dti. As far as we could establish, there has not been a recent review of the key funding instruments and programmes in innovation and business support, including the THRIP and the Support Programme for Industrial Innovation (at dti) and the different instruments managed by TIA (Technology Stations Programme).

We conclude with two recommendations that pertain to improved efficiency and oversight of public expenditure on R&D.

Recommendation:
A study should be conducted to assess the extent and possible synergy between the investments of the universities, funding agencies (NRF, MRC, WRC) and government departments (DHET, Department of Water Affairs and Forestry, Department of Health) in building the next generation of scientists and scholars in the country

Various departments and agencies as well as all the universities in the South African STI system invest significant funds in building the academic and scientific pipeline. This funding includes various bursary and scholarship schemes, as well as grants to post-doctoral fellows, emerging scholars and early career academics to enable them to become established scientists and scholars. We recommend that a study be undertaken (1) to establish the quantum of public investment in this area; and (2) to identify possible areas of duplication as well as synergy for better coordination.

Recommendation:
An appropriate quality M&E framework needs to be implemented to ensure that the DHET publication funding system adheres to good practice in responsible research

Studies conducted by CREST (commissioned both by ASSAf and the DHET) have revealed that the current publication funding system (which disburses more than R2.4 billion annually to the universities) has been hugely effective in stimulating growth and productivity among university academics. Unfortunately, the system has also led to various unethical and fraudulent publication practices. In two recent studies, we have unearthed compelling evidence of significant abuse and gaming of the subsidy framework through publications in predatory journals, excessive claims for publication outputs, clear and evident gaming of subsidies linked to conference proceedings, as well as increasing evidence of unethical behaviour by journal editors. The aim of the implementation of the proposed framework would be to assess and re-affirm both the quality and integrity of publications by South African academics.

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