29 May 2020

MONITORING AND EVALUATION FRAMEWORK FOR THE SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION SYSTEM

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

NACI
NATIONAL ADVISORY COUNCIL ON INNOVATION

The National Advisory Council on Innovation (NACI) has been created by legislation and the NACI Council is appointed by the Minister for Science and Innovation. The National Council on Innovation Act, 1997 (Act No. 55 of 1997), provides the mandate for NACI (2015) to advice to government, through the Minister of Science and Technology, on a range of issues related to Science, Technology and Innovation (STI).

Published by:
The National Advisory Council on Innovation (NACI)

National Advisory Council on Innovation
Suite L2, Enterprise Building
Mark Shuttleworth Street
The Innovation Hub
Pretoria
0087

The NACI Secretariat
Private Bag X894
Pretoria
0001

NACI Secretariat
Tel: 012 844 0252
Email: naci@dst.gov.za
www.naci.org.za

NATIONAL ADVISORY COUNCIL ON INNOVATION

Table of Contents

innovation for a better future

Foreword

The National Advisory Council on Innovation (NACI) is mandated to provide advice to government, through the Minister of Science and Technology, on a range of issues related to Science, Technology and Innovation (STI). It achieves its objectives through collaboration with local and international experts, organisations and institutions.

Recent reviews of the National System of Innovation (NSI), such as the 2012 Ministerial Review on the STI Landscape and the draft new White Paper on STI have identified Systemic Monitoring and Evaluation (M&E) as one of the weaknesses facing the NSI. There are different M&E activities happening across the system. NACI has been monitoring selected indicators and published results (in the form of STI Indicators Booklet) annually, and established the initial phase of the National STI data and information portal in 2017.

In March 2019, Cabinet approved a new White Paper on STI. The White Paper strongly advocates for the strengthening of the M&E capability to bolster policy performance. Among others, it assigns NACI to develop the NSI M&E framework.

The development of the White Paper coincided with stakeholder engagement that NACI had initiated focusing on building NSI M&E capability. This was in line with its Strategic Plan ambition. Stakeholders identified and confirmed findings of some systemic reviews about the absence of an M&E framework and system for the NSI as a major weakness, and one that required urgent attention. NACI then partnered with the DSI/NRF Centre of Excellence in Scientometrics in Science Technology and Innovation Policy (SCiSTIP) to provide technical support. A draft M&E Framework was generated and presented at the Round-Table Discussion on 10 September 2019, at the Sheraton Hotel, Pretoria. Overall, stakeholders welcomed the draft M&E Framework and offered suggestions on how it could be enhanced further. This was followed by written comments which were all incorporated into the final framework approved by NACI.

Therefore, this M&E Framework needs to be viewed as an important step towards building a M&E capability as envisaged by the White Paper. The development of a M&E framework was a complex and challenging process, and context needed to be considered. The M&E framework was developed for the country rather than just one stakeholder or actor and, while robust, should be flexible enough to accommodate future changes to policy. NACI welcomes comments and recommendations, which will form the basis of the next step, including establishment of an M&E system. The email address to use for submitting comments on this framework is naci@dst.gov.za.

Dr Mlungisi Cele

____

Acting CEO
National Advisory Council on Innovation (NACI)

Acronyms

ASSAf	The Academy of Science of South Africa
DST	Department of Science and Technology
NRF	National Research Foundation
NACI	National Advisory Council on Innovation
CHE	Council on Higher Education
M&E	Monitoring and Evaluation
STI	Science, Technology and Innovation
NSI	National System of Innovation
DPME	Department of Planning, Monitoring and Evaluation
R&D	Research and Development
dti	Department of Trade, Industry and Competition
DHET	Department of Higher Education and Training
NGO	Non-Governmental Organization
CeSTII	Centre for Science, Technology and Innovation Indicators
ToC	Theory of Change
BRICS	Brazil, Russia, India, China, South Africa
SCiSTIP	DSI/NRF Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy
CoE	Center of Excellence
TBE	Theory-Based Evaluation
SME	Small to Medium Enterprise
SDGs	Sustainable Development Goals
CPSI	Centre for Public Service Innovation
TIA	Technology Innovation Agency
IDC	Industrial Development Corporation
NDP	National Development Plan
NSTF	The National Science and Technology Forum
SARChi	The South African Research Chairs Initiative
RoA	Return on Assets

Acknowledgements

We would like to acknowledge the significant contributions of various individuals to this report:

- Michael Kahn (Appendix 1), Lynne Lorenzen (Appendix 2), Lauren Wildschut (Appendix 3), Thomas auf der Heyde (Section 2.3) and Rodrigo Costas (section on altmetric indicators)
- Marthie van Niekerk for various contributions to the text and the overall project administration;
- The team of experts for their contributions prior and at our 2019 March workshop in Stellenbosch (Prof. Giorgio Sirilli, Prof. Nick Vonortas and Prof. Ulrich Schmoch) and other participants from CREST, NACI, DST and CESTii.

The final version of the report has also greatly benefitted from the oral or written comments by participants at the M&E Framework Consultative Seminar on October 10th, 2019 at NACI (Pretoria).

Prof. Johann Mouton and Prof. Robert Tijssen (SciSTIP)

Executive Summary

In 2017 the National Advisory Council on Innovation (NACI) requested SciSTIP to develop an M&E framework for the Science, Technology and Innovation (STI) system in South Africa. Meanwhile, in March 2019, South Africa's Department of Science and Technology (DST) has published *'White Paper on Science, Technology and Innovation: Science, technology and innovation enabling inclusive and sustainable South African development in a changing world'* (March 2019). Against this background, and the status quo in South Africa where multiple entities regularly commission evaluations and reviews at all levels of the STI system, what should a *'Monitoring & Evaluation'* (M&E) framework for the entire SA STI system look like?

The *White Paper* states the following list of main factors constraining South Africa's STI performance:

- Inadequate and non-inclusive means of agenda setting;
- Lack of policy coherence and coordination;
- Inadequate mechanisms for policy learning;
- Insufficient involvement of business and civil society;
- Inadequate high-level SET and technical skills for the economy;
- A research system that, although productive, is small;
- An environment that does not sufficiently enable innovation;
- Significant levels of underfunding.

The proposed M&E framework in this document addresses one of these constraints in particular: 'Inadequate mechanisms for policy learning'. Our framework is designed to enhance those learning processes. A workable and effective framework requires a sound theoretical and understandable foundation, a transparent and applicable analytical model, as well as appropriate information sources and 'contextualised' performance indicators. The M&E rationale underpinning the framework should incorporate the views and interests of all major stakeholders and actors in the STI system, where the public sector and the private sector perspectives are taken into account.

As indicated in the NACI Terms of Reference, the framework deals with the overarching 'systems' level (not at the sector level, program level or any other sub-level). Developing a systems-level M&E framework is challenging. Our proposed multi-perspective framework, introduced in section 2 of this report, builds on decades of M&E traditions and best practices in South Africa and elsewhere, by applying the following five core components in the framework: (a) an adaption of the National System of Innovation; (b) '*Theory-Based Evaluation'* (TBE) derived from a *'Theory of Change'* and an associated *'Logic model'*; (c) an integrated set of '*domain-specific evaluation questions'* and *'system-level evaluation questions'*; (d) applying a wide range of quantitative performance indicators; (e) introducing M&E information platforms, such as an *STI Scoreboard* with an *STI Index*, to track and measure the general performance of the entire system and how it moves forward.

These building blocks refer to the key issues that any high-quality M&E framework needs to address: a suitable ToC is essential, as is selecting the most appropriate evaluation criteria, and applying those analytical methods and data sources that are able to follow general developments in the system as well as identifying the effects of system interventions or new STI policies. Only then will we get the right kind of empirical input and feedback to appreciate the workings of the STI system, assess its state of development, and gauge future prospects. The framework design should minimize the risk of adopting a wrong ToC, selecting inappropriate indicators or implementation plans. Design failures might lead to sub-optimal M&E practices, introduce misguided performance incentives, or incentivise inappropriate behaviour, unintended outputs or negative impacts on the STI system.

Our proposed (draft) framework makes a clear distinction between 'monitoring' objectives and 'evaluation' goals. The M-part, elaborated in section 5, 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 take cues from the 'European Innovation Scoreboard' as a particularly interesting 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 SA STI system: international and domestic benchmarking. Our analysis of the currently available indicators, and how they map onto the structure of the STI model, offers many options for applications in M&E settings, but it also reveals important information gaps and missing indicators that need to be developed.

The E-part of the M&E framework, described in section 6, applies the TBE 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 abovementioned *White Paper* provide one input for the structuring. Other relevant questions relate to systems-level issues in SA STI domains, but may also derive from international and global trends in STI. A M&E framework of the STI system requires a tailor-made approach with a strong emphasis on the connectivity between actors and processes with the system, both national and international – adopting a *'National System of Innovation'* model is not sufficient to accommodate these requirements.

As for implementation issues, section 7 addresses the context in which the M&E framework will eventually be organized, embedded and applied. Special attention will have to be paid to M&E at the level of targeted STI system components, such as STI domains and institutional actors, and dedicated STI policy interventions. Effective management of an M&E framework and implementation of M&E activities, with appropriate ToCs and performance indicators, will critically depend on whether or not the essential conditions are in place with regards to system governance, its resourcing, and how the varying interests of the system's major stakeholders are reflected and secured.

Summarising, building on a general introduction of the SA STI system, the above White Paper, and relevant methodological considerations such as the TBE approach and international best practices (such as the European Innovation Scoreboard), this document provides an outline for such a framework and its main components. Our outline includes practical suggestions for analytical models, classes of performance indicators, data collection methodologies and measurement models. It also contains a set of suggestions that NACI can take under advisement with regards to aim, scope and structure of implementing such a framework.

Chapter 1

Section 1

Introduction

1.1 Background of this report

The National Advisory Council on Innovation (NACI) requested SciSTIP in mid-2017 to submit a proposal to develop an M&E framework for the Science, Technology and Innovation (STI) system in South Africa. In response to the request and its Terms of Reference, SciSTIP submitted a proposal (November 2017) and subsequently an Implementation Plan in June 2018. The contract for this work was finalised in January 2019. Meanwhile, South Africa's Department of Science and Technology (DST) has published *'White Paper on Science, Technology and Innovation: Science, Technology and Innovation enabling inclusive and sustainable South African development in a changing world'* (March 2019). The White Paper states: *"NACI will be reconfigured to act as the national STI M&E institution, charged with analysing STI information and undertaking work to inform government planning on STI".* This formulation suggests a quite centralised approach to M&E of the STI (housed at NACI) as well as a specific purpose (to inform government planning). Against the background of the status quo in South Africa, where multiple entities regularly commission evaluations and reviews at all levels of the STI system, what should a 'Monitoring & Evaluation' (M&E) framework for the entire SA STI system look like?

To address this key question a SciSTIP preparatory Expert Workshop was organised, at CREST in Stellenbosch, on March 19th and 20th 2019. Some 15 participants, including several invited international experts on STI evaluation, as well as two NACI representatives, attended this meeting. The aim was to discuss the various 'good practice' options available for such an M&E framework within the SA context, and decide on the most appropriate way forward to develop such a Framework. Various supporting documents were prepared before the workshop. These include:

- A document entitled: Overview of conceptual frameworks for Monitoring and Evaluation Systems for a Science, Technology and Innovation System (Botha and Tijssen);
- A document entitled: "Workshop on a M&E framework for the SA STI system: An annotated preparatory document" (Mouton and Tijssen);
- A document entitled: "Patent analysis for South Africa" (Schmoch).

In addition to these documents a number of preparatory activities were undertaken before the workshop:

- A literature search of relevant documents on STI indicators was conducted by the CREST Information officer (this resulted in more than 50 relevant documents that were subsequently scanned and uploaded to the CREST STI Indicator Bank). A CREST research assistant, Lebo Lerato, was given the task (under the supervision of Prof. Mouton) to work through these documents and identify all indicators into an Excel spreadsheet. A first version of this work was completed by the end of February. Further work was done by two senior researchers at CREST in order to clean up the indicator list into a more appropriate and comprehensive 'indicator bank'.

The first version of this report was presented at a M&E framework seminar on October 10th, 2019 at NACI (Pretoria). The constructive conversation and feedback from the 80 participants during this 3 hour meeting, as well as a dozen written commentaries that were submitted to the authors afterwards, significantly improved the content and structure of the final report.

1.2 Historical background

South Africa's NSI and STI system has witnessed major developments since the early 20th century - see **Appendix 1 for a short historical overview**. The system has also undergone a large series of reviews and evaluations between 1996 and 2019 at various levels of the STI system. **Table 1** provides a summary overview of these studies. A detailed list of these reviews and evaluations is found in **Appendix 2**. Although the proposed M&E framework in this report primarily addresses the 'top level' perspective of the entire South African national STI system, which a comprehensive framework should also be able to accommodate lower-level M&E activities (we will return to this issue in Section 7.3).

Table 1: Summary of completed reviews and evaluations of the SA 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
	Technology and innovation programme reviews	3

We have not conducted a proper meta-analysis, or even systematic review, of these studies. It would, therefore, not be appropriate to draw too strong conclusions from this overview. However, some preliminary observations are relevant as a backdrop to the development of the M&E framework:

- 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 co-ordination 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 is 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 many reviews within short spaces of time.
- 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.

1.3 General structure of the report

Section 2 is devoted to a discussion of the two core notions of 'monitoring' and 'evaluation' in the proposed M&E framework. **Section 3** presents the argument for a theory-based approach to the M&E framework (a short history of TBE is summarised in **Appendix 3**). The conceptual framework that is used in this report to describe and analyse the science, technology and innovation system in the country is discussed in **Section 4** (against the background of a review of different conceptual frameworks that we have undertaken. The two main sections of this report (**sections 5 and 6**) respectively presents the outline of a **SA STI Scoreboard** for monitoring the performance of the system; and an Evaluation framework for addressing system-wide and domain-specific evaluation questions (**Appendix 4** lists the various domain-specific questions extracted from the White Paper). The report concludes (**Section 7**) with a number of issues that need to be addressed in implementing the M&E framework proposed in this report.

Section 2

Defining monitoring and evaluation

2.1 Designing an M&E framework

Developing a comprehensive and workable M&E framework, for any kind of social system, is a challenging undertaking. Sectoral systems such as educational, or health systems, are complex entities in many respects. The same applies to Science, Technology and Innovation systems. Such systems are typically open systems (Bhaskar, 1979) that constantly change in response to exogenous factors in their environments as well as because of endogenous factors (such as changes in policy and strategy). A national STI system typically consists of a multitude of institutions and organisations (public and private) whose missions, strategies and portfolios change over time. Linkages, interactions and resource flows between these entities are also not static; they respond and adapt to new demands and priorities in their ecosystems.

According to Markiewicz and Patrick (2016: p.1-2)[1] an M&E framework:

- is both a planning process and a written product designed to provide guidance to the conduct of monitoring and evaluation functions over the lifespan of an initiative;
- includes an overarching plan and a step-by-step guide to its operationalisation and application over time;
- defines the parameters of routine monitoring and periodic evaluation that will take place over the life of a program or initiative;
- shows how information and quantitative data are collected, aggregated and analysed on a regular basis in order to answer the agreed evaluation goals or questions. The data generated should support formative and summative evaluation processes.

Guided by these design criteria a carefully designed M&E framework needs to:

- be developed concurrently with, and to inform, an overarching plan or design;
- derived from an overall programme theory and/or based on an analytical model
- ensure constant alignment between missions/goals and funded organisations, infrastructures, programmes or other activities and investments;
- specify the monitoring strategies, as well as any studies, reviews or evaluations to do;
- guide and inform the performance monitoring of those activities/investments, and allows for tracking progress against a strategy or master plan;
- guide and inform the outcome mapping of those activities/investments, and provide the means to identify and assesses expected and unexpected results or impacts;
- guide and inform studies to be conducted or commissioned to evaluate outputs, outcomes and impacts;
- allows for generating and disseminating knowledge about good practice and programme progress;
- ensure optimal use of M&E results for purposes of organisational and policy learning, strategic planning and decision making.

The scope of such an M&E framework should include a mix of 'deductive' (top-down) elements:

- overview of specific issues, goals and problems;
- political or strategic issues;
- informed by generally-accepted theoretical or conceptual notions;
- incorporating country and sector specificities;
- choice of benchmarking entities (countries, regions)

… but also, several more 'inductive' (bottom-up) elements, like:

[1] *Markiewicz, A. & Patrick, I. (2016). Developing Monitoring and Evaluation Frameworks, Thousand Oaks, CA: Sage Publishers.*

- adopting on international 'best practices' with regards to analytics and measurement models
- driven by accessible high-quality empirical data;
- incorporating established (key) performance indicators;
- opportunities to develop and implement new, 'customised' information sources and indicators.

2.2 The logic of evaluation

We need to be clear about the meaning of the central notions of 'monitoring' and 'evaluation'. The huge literature about programme evaluation (which originated in the 1960's in the USA), the emergence of a dedicated field of R&D evaluation in the 1970's and the more recent institutionalisation of performance monitoring which arose out of the New Public Management paradigm of the early 1990s have resulted in a multitude of definitions of 'monitoring' and 'evaluation' as well as diverse approaches to conducting (performance) monitoring and evaluation activities. It is therefore important that we begin this report by making it clear on how we define these two key notions, and what our approach to M&E is. As to the first challenge, we take as point of reference, the classic definition of 'evaluation' provided by one of the pioneers of evaluation theory – Michael Scriven. Scriven introduced the term 'the logic of evaluation' in 1980 and defined it as follows:

> *"The most common type of evaluation involves determining criteria of merit (usually from a needs assessment), standards of merit (frequently as a result of looking for appropriate comparisons) and then determining the performance of the evaluand so as to compare it against these standards" (Scriven 1980).*

For Scriven, criteria determination involves identifying the dimensions on which the 'evaluand' (the object of our assessment or evaluation) must do well to be assessed as being good. Standards of merit tell us how well the evaluand must do on each dimension to be good. He distinguishes between absolute standards (such as a certain minimum safety level that all automobiles must attain) or comparative standards (when we compare the evaluand to available alternatives). And finally, we assess the performance of the evaluand by measuring the evaluand (gathering appropriate data and observations about the evaluand on each dimension) and then comparing the results to the standards of merit. The end result for Scriven is an evaluative judgment of the evaluand. The logic of 'e-valuation' is indeed the logic of how we make value judgements that are evidence-based. To illustrate Scriven's logic, we apply it to the domain of science, technology and innovation. Scriven's definition requires us to address three questions:

1. What is the object of our (monitoring and) evaluation (the evaluand)?
2. Which aspects or dimensions of the evaluand are being monitored and evaluated?
3. Against which standards of merit will we base our judgment of whether the evaluand is performing well?

Figure 1: Visualisation of the logic of evaluation applied to the domain of STI

Evaluand: The object of evaluation	**Criteria of determination**: Dimensions on which the evaluand must do well	**Performance targets, standards, criteria**: How well must the evaluand perform, on each dimension, to be regarded as "good"
Objects: STI system STI programmes Institutional sectors Organisations or organisational units Fields and domains Teams and individuals	General dimensions: Coherence/integrity Goal attainment Transformation Sustainability Production/productivity Efficiency/effectiveness Relevance/impact Quality/ excellence Inclusivity/transformative change	Performance frameworks: National objectives Programme goals Organisational targets International quality standards Domestic quality standards

The first block in **Figure 1** highlights the fact that we need to distinguish between different levels of M&E: the objects of evaluation are located at different levels: the entire system (or sub-systems), STI institutions (such as universities or science councils or firms), scientific fields, STI programmes (science funding programmes, research capacity building programmes, technology and innovation support programmes) and even individuals (scientists, engineers and entrepreneurs).

The second block refers to the aspects or dimensions of the evaluation objects that we want to monitor and/or evaluate (Scriven's 'criteria of determination'). It should be self-evident that the criteria of determination will differ according to the level of the evaluand. We do not assess the 'performance' of the entire system using the same criteria as we do for assessing the performance of institutions, programmes or individuals. Which criteria are deemed to be appropriate for monitoring and evaluating the performance of the entire (STI) system will be informed by the system's goals and objectives. These are often incorporated in national policies or strategies. Which criteria are deemed to be appropriate for evaluating the performance of an institution (such as a science council or university), will be informed by the institutional missions, goals and objectives of the institution.

The third block incorporates Scriven's point that evaluation is always about making a judgement about the merit or worth of something – how well we are doing on a specific dimension. Making a value judgement typically involves some form of comparison. We can distinguish between four kinds of comparisons:

- Comparing performance against a standard;
- Comparing performance against a target;
- Comparing our current performance on X against prior performance on X;
- Comparing our performance against other 'similar' objects (systems/ institutions).

We will elaborate on what each of these forms of comparison or benchmarking means in practice later in the report. But it is already clear that a number of questions in this regard remain to be addressed. Who sets these standards? And by what authority? What do we do in cases where there are no explicit standards? Should we not distinguish between international and local (national) standards? And how do we deal with standards that change over time? Who sets targets and how are they set? Who decides what a realistic or unrealistic target is? We will address these questions in later sections of the report. Suffice to say at this stage, that we will use the term 'benchmarking' as the appropriate term to capture Scriven's ideas of 'comparing against a standard'.

Assessing the performance of the evaluand requires measuring the evaluand (on each dimension) and comparing the results to performance standards, targets or other indicators of merit. What we would regard as the appropriate evaluation dimensions and criteria for a specific evaluation study or review are always context- and time-bound. What is regarded as an appropriate criterion today, may not be so in twenty years' time. What is appropriate to the USA may not be appropriate to South Africa. Higher-order discourses in the field of STI in South Africa today around transformation, social impact, sustainability and alignment with national goals (NDP) and the sustainable development goals (SDG's) all influence our choice of evaluation criteria and hence our evaluation practices.

For Scriven the act or process of evaluating something includes (even if implicitly) the process of monitoring (or close observation) of the object of evaluation. Taking Scriven's definition of evaluation as point of departure, which does not address the issue of 'monitoring' as a separate issue, Box 1 provides an elaboration on how these two concepts interrelate.

Box 1. Monitoring and evaluation

Monitoring and evaluation are often inextricably linked: evaluations provide guidance for what kind of monitoring (indicators and data) evidence is required; monitoring data is often required in informing evaluative judgments.

Our everyday notion of monitoring refers to relatively frequent observations (as in surveillance) or repeated measurement of some object or activity. In the context of programme monitoring this then typically gets associated with the frequent and standardised observation (measurement) of programme activities, outputs, outcomes and impacts. The mechanism through which such programme monitoring is achieved is through a set of standards (consistent), quantitative indicators or metrics. But the use of indicators is not confined to the programmatic level. Systems performance and organisational or institutional performance is also increasingly captured in sets of indicators or metrics based on frequent and regular measurements.

A common misconception is that monitoring is a purely descriptive (and hence neutral or non-evaluative) undertaking. Although it is true that one can – at its most basic level – define monitoring simply as counting activities (attendances of conferences) or outputs (number of scientific papers, doctoral graduates or patents), produced by a system or an institution, it should be clear from the discussion thus far (if we follow Scriven's logic of evaluation), that the monitoring of the properties of objects only becomes meaningful and relevant within the context of evaluation. It is only when we set standards (or norms or even targets) of what counts as 'good' or 'worthwhile', that monitoring is a useful endeavour. In fact, monitoring against some standard or target or comparable entity is nothing but performance monitoring and benchmarking.

We began this section by arguing that the notions of 'monitoring' and 'evaluation' – although often seen as two separate activities - are in fact inextricably bound together by what Scriven calls the 'logic of evaluation". But there are, of course, also differences between monitoring and evaluation activities.

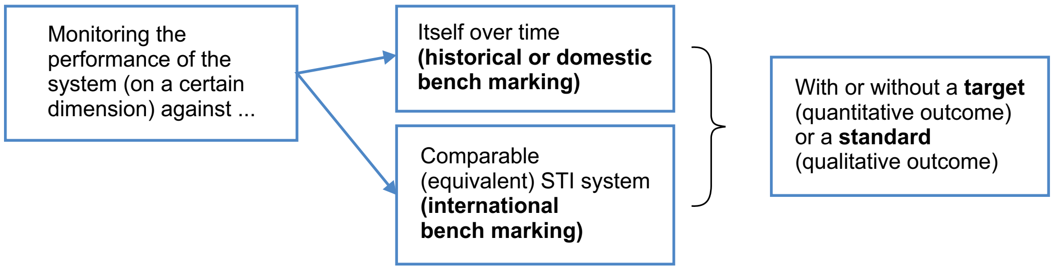
2.3 Monitoring questions

2.3.1 Introduction

The term 'monitoring' refers to the relatively frequent or repeated measurement of some object or activity. The different 'types' of monitoring are exhibited in **Figure 2**. In the context of programme monitoring this then typically gets associated with the frequent and standardised observations (measurement) of programme activities, outputs and outcomes. It is precisely because monitoring something means that one requires repeated observations, that monitoring is associated with indicators and indicator systems.

Only if the repeated measurement of the evaluand is done by using the same (standardised) measures or indicators, will it produce reliable data and evidence on the performance of the evaluand. But the use of indicators is not confined to the programmatic level. Systems performance and organisational or institutional performance is also captured in sets of indicators or metrics based on frequent and regular measurements.

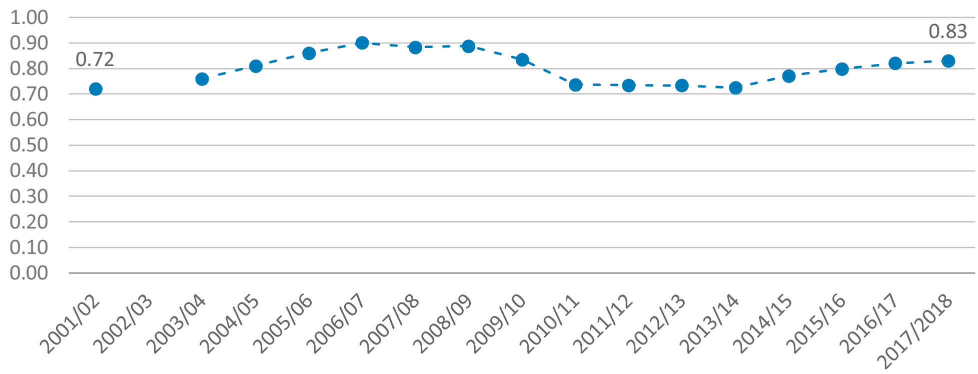
Figure 2: Main types of monitoring



2.3.2 GERD/GDP as a STI performance indicator

To illustrate the differences between the notions of 'monitoring', 'performance monitoring' (against a target) and (international) 'benchmarking', we take as an example one of the most well-known STI indicators viz. Gross domestic expenditure on R&D as proportion of Gross Domestic Product (GERD/GDP). The graph below first presents the time-series monitoring data on this indicator for South Africa. This shows that GERD/GDP has remained fairly stable (with some intermittent increases and decreases) at around 0.80% over the past twenty-years (see **Figure 3)**. Monitoring the performance of some objects (in this case the investment in R&D in South Africa) over time, is thus defined as domestic or historical benchmarking as one compares the performance of the system with itself over time[2].

Figure 3: South African GERD level as a percentage of GDP (2001/2002-2017/2018)



Sources: South African R&D Survey and OECD. Stat

However, the South African government has, in various policy and strategy documents since 2002, set a target of 1.0% of GDP (in some cases even a target of 1.5%) to be spent on R&D by 2020. If we judge the performance of SA on this indicator against this target, we must conclude that SA's performance on this indicator is disappointing. This is an example where we undertake historical benchmarking of the performance of the system on one dimension (R&D intensity) *against a (policy) target.* There are a number of other examples to be found where SA science and innovation policies have set targets, for example, for the production of PhD's (5000 by 2030) or SA's world share of scientific publications in the Web of Science (1% by 2018) and so on.

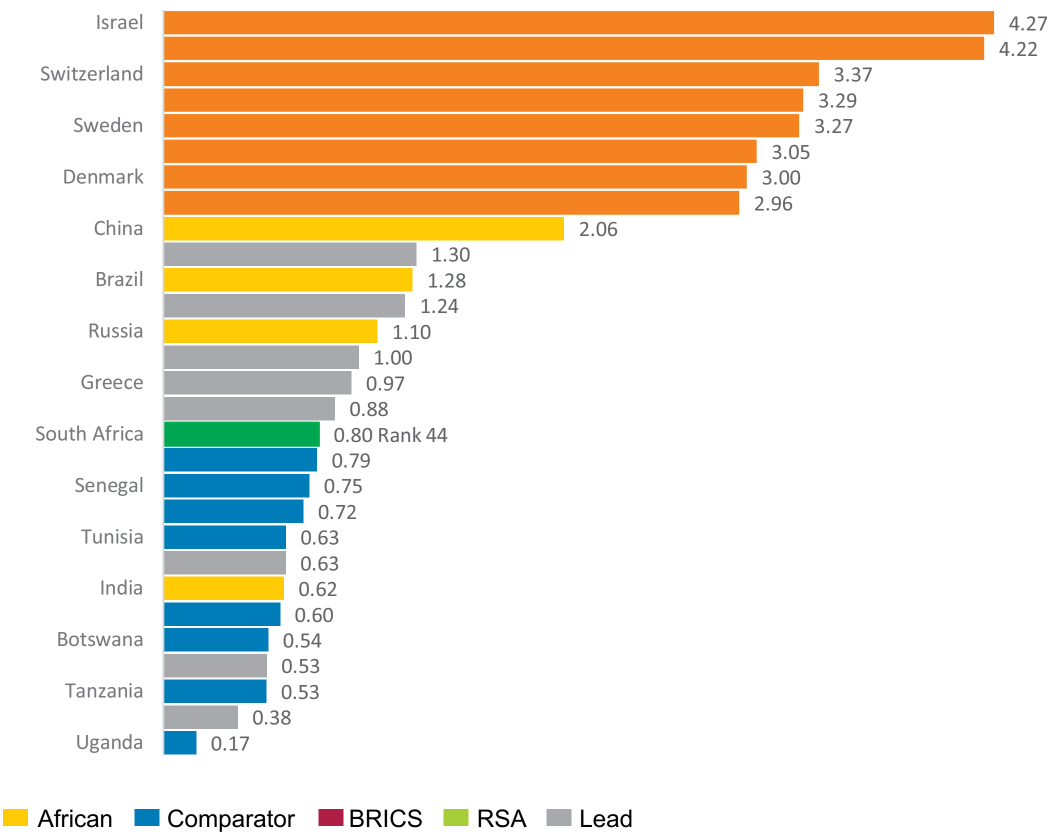
[2] *In programme evaluation terminology this is also referred to as 'reflexive control' measurement: measuring an object against itself as the control.*

Wherever a target has been set, it opens up the possibility not merely to look at trends over time (whether there are increases or decreases or no change), but also to make a judgment of whether the system has performed well or not.

The second main form of benchmarking involves a comparison SA's performance with other countries, viz. international benchmarking. The key issue then – as in all form of comparison – becomes which countries one selects for such a comparative benchmarking exercise. In a recent report[3], CREST selected four sets of countries (Lead countries, comparator countries, selected African countries and the BRICS countries) against which to benchmark our performance on investment in research, human resources and research performance.

As far as our example indicator (GERD/GDP) is concerned, the results showed that South Africa is currently ranked 44th in the world (latest available data). Compared to comparator countries, South Africa is ranked 6th; to the other BRICS countries 4th (behind China, Brazil and Russia). In Africa, South Africa is the highest ranked country on this indicator. The eight lead countries spent between 2.96% to 4.27% of GDP on R&D, whereas the comparator countries range from 0.38% to 1.30%. The BRICS countries range from 0.62% for India to 2.06% for China, while the selected African countries ranged from 0.17% to 0.79%. This is shown in **Figure 4**.

Figure 4: GERD/GDP performance for selected countries (2015 or most recent)



Source: UIS.Stat; South African R&D survey (CeSTII 2018)

[3] *CREST (2019). The state of the South African research enterprise. Stellenbosch University.*

2.4 Evaluation questions

Whereas monitoring is a regular activity that is most effective and useful the more often it is conducted, evaluations are typically more ad hoc and are undertaken to address specific policy, strategic and programmatic considerations as these arise. As discussed above, although evaluations can and do utilise monitoring data (in the form of indicators) they typically also utilize a whole range of other sources of evidence to come to final value-judgements about different aspects of the evaluand. These would include qualitative and narrative data sources (individual interviews, focus-group interviews), surveys (including 'Delphi-type' surveys), use of expert groups, meta-analyses, data-modelling, and so on.

To arrive at evidence-based judgments, evaluation addresses specific evaluation criteria - such as productivity, effectiveness, efficiency, inclusivity, diversity, relevance and sustainability - and is supported by a wide spectrum of background and foreground information as well as selected indicators. These indicators can be either 'quantitative' (based on measurement and statistics), or 'qualitative' (extracting their information from sources such as interviews or case studies). We discuss evaluation questions in the STI domain in more detail in Section 6.

Section 3

Theory-based approach to M&E

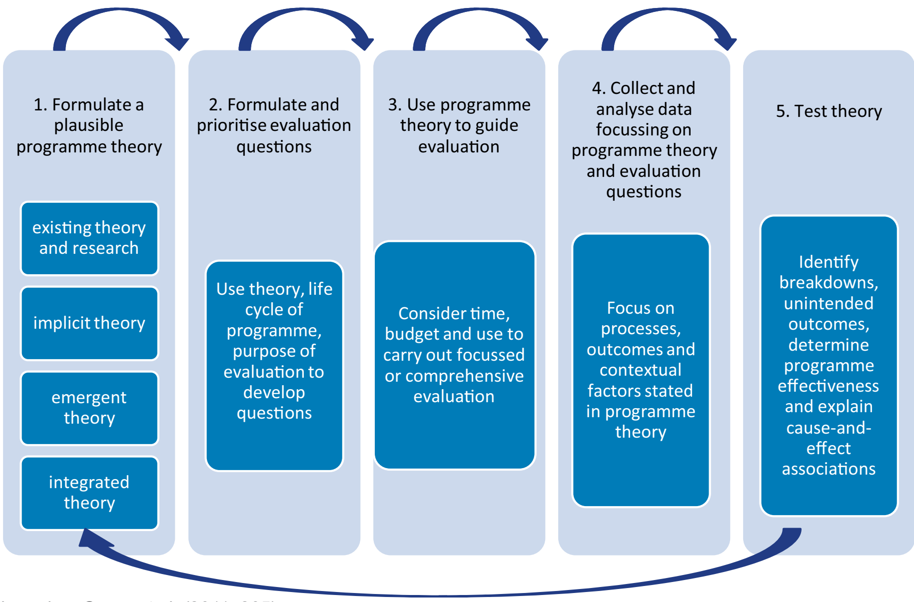
3.1 The need for a theory-based approach to M&E

Monitoring and evaluation activities are typically undertaken for different aims and purposes and hence serve different functions for different stakeholders. Monitoring, and specifically performance monitoring, forms an integral part of the accountability regimes of the public sector. Reliable and accurate information about the performance of government in its key areas of responsibility – education, health, basic services, security, economic growth and job creation and the quality of life of its citizens – is essential for evidence-based resource allocation (funding) as well as the improvement of all its services. Evaluations address more qualitative questions about the relevance of what we do; whether it is effective and have the required impact and whether our results are sustainable and scalable. Also, evaluation should inform future policy, strategy and implementation. Summarising, monitoring and evaluation activities have the following multiple (and mutually reinforcing) purposes:

- accounting for public funds and investments;
- informing strategic planning;
- contributing to formative purposes to improve through learning;
- contributing to summative purposes to make decisions about resource allocation and priority setting.

A M&E framework is, basically, a learning tool to help grasp and understand changes and developments over time. It should strive to be informative and data-based rather than driven by political ideologies or current fads and fashions. The question then becomes what gets included in a M&E framework? Which indicator categories and specific indicators are selected for inclusion in the monitoring part of the framework? What evaluation criteria and questions are included in the evaluation part of the framework? There is consensus in the M&E literature that the selection of indicators or evaluation questions should not be made on the basis of the available measures or data. M&E frameworks should be **data-based** but not **data-driven**. Stated differently: there are numerous examples of monitoring reports (including indicator reports) where a specific indicator is included simply because of the availability of data for that indicator. M&E frameworks that are driven by the data typically have no conceptual integrity or cohesion and hence, are less likely to inform any kind of learning. Over the past thirty years, most evaluators have come to accept that M&E should be embedded in some higher-order conceptual model or 'theory'. This approach has become to be known as a theory-based approach to M&E. The historical development of *'theory-based evaluation'* (TBE) is described in **Appendix 1**.

Figure 5: Circular TBE process



Source: based on Coryn et al. (2011: 205)

In one of the more recent developments, Coryn et al. (2011) define five core elements in a TBE process: (a) theory formulation (b) theory-guided question formulation (c) theory-guided evaluation design, planning, and execution, (d) theory-guided construct measurement, and (e) causal description and causal explanation. Figure 5 is based on their description of 'circular TBE', comprising a sequence of five steps in the TBE process:

1. Formulate a plausible programme theory
    - TBE is a form of evaluation that illuminates the set of cause-and-effect relationships in a system or programme. According to Coryn *et al.*, 2011 this theory can be:
        - based on existing theory and research (e.g. social science);
        - implicit i.e. based on the unarticulated assumptions and experience of programme staff;
        - emergent i.e. developed from data collection (e.g. observations and interviews);
        - developed by an evaluator or integrated i.e. based on the best combination of all previous types of theories listed.
2. Formulate and prioritise evaluation questions
    - TBE utilises a theory of change to develop evaluation questions, but the life cycle and evaluation purpose should also determine the process of prioritisation of evaluation questions.
3. Use programme theory to guide evaluation: design and methodological parameters
    - TBE should guide the focus of the evaluation, but time, budget and the proposed use of the evaluation will also play a role in decision regarding which elements of the system or programme and theory are focused on during the evaluation.
4. Collect and analyse data, focussing on programme theory and evaluation questions
    - TBE should result in the collection and analysis of data at critical points that are primarily determined by the theory, but also generally by evaluation questions.
5. Test the theory
    - TBE should systematically test the articulated theory and indicate if a breakdown occurs at a particular point in the theory.

Although TBE has its origins in the field of programme evaluation, it is important to point out that the five steps above apply to policies or interventions at the level of the entire STI system as well as its lower levels, such as industrial sectors, institutions, fields of science, technology area, and higher educational programmes.

3.2 Theory of Change and the Logic model

The Theory of Change (ToC) is a conceptual tool that explains the (anticipated) processes of change by outlining the causal linkages in a system or programme, i.e., its shorter-term, intermediate, and longer-term outcomes. The identified changes are mapped – as the 'outcomes pathway' – showing each outcome in logical relationship to all the others, as well as chronological flow. The links between outcomes are explained by 'rationales' or statements of why one outcome is thought to be a prerequisite for another.[Carol Weiss popularized the term 'Theory of Change' in 1981 as a way to describe the set of assumptions that explain both the mini-steps that lead to the long-term goal of interest and the connections between activities and outcomes that occur at each step of the way. She challenged designers of complex community-based initiatives to be specific about the theories of change guiding their work and suggested that doing so would improve their overall evaluation plans and would strengthen their ability to claim credit for outcomes that were predicted in their theory. She called for the use of an approach that, at first glance, seems like common sense: lay out the sequence of outcomes that are expected to occur as the result of an intervention, and plan an evaluation strategy around tracking whether these expected outcomes are actually produced.

The ultimate success of any ToC lies in its ability to demonstrate progress on the achievement of outcomes. Evidence of success confirms the theory and indicates that the initiative is effective. Therefore, the ToC outcomes must be coupled with indicators that guide and facilitate measurement. Indicators may be said to operationalise the outcomes – that is, they make the outcomes understandable in concrete, observable and measurable terms

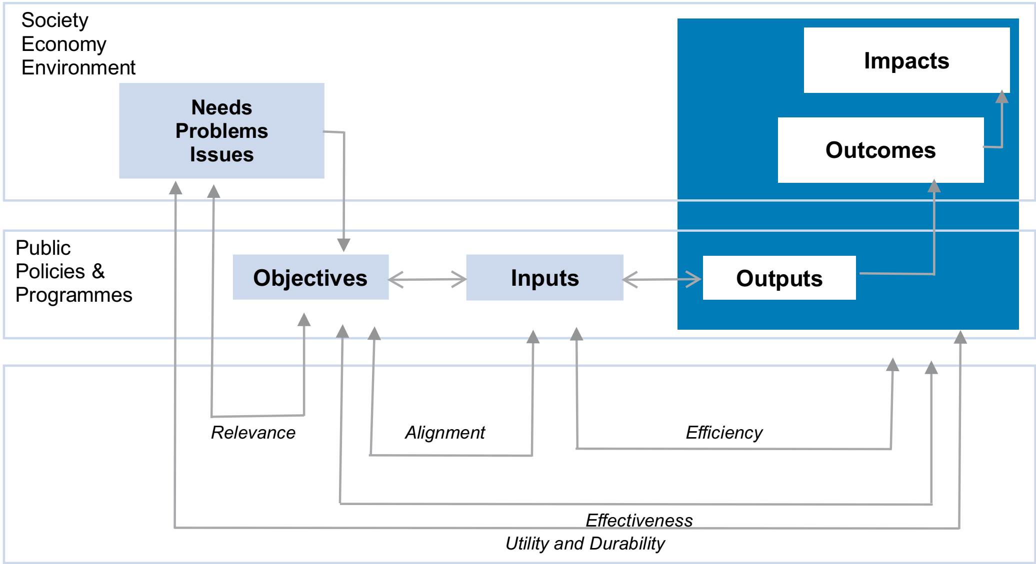
ToCs come in various forms: as visual diagrams, outcome maps or in narrative form (as a series of 'IF-THEN' statements). One source of confusion relates to the difference between a theory of change and the Logic model (or Log frame). First, it is important to emphasize that both are 'conceptual tools' that are used within TBE-approaches. Both tools attempt to capture the causal pathways and linkages either within systems or programmes. Because these two 'tools' are complementary in making sense of how interventions lead to particular outcomes and impacts, they are often equated or simply confused. However, there are important differences: while ToCs tend to be high-level 'generic' descriptions of those desired outputs, outcomes and underpinning processes, Logic models and Log frames are basically the tools to empirically assess those achievements within a policy-oriented framework. These 'change models' incorporate time-bound and detailed articulations of specific needs and inputs, as well as causal pathways and ultimate goals. The focus on a 'theory of change' is on the causal pathways and the conditionalities embedded in cause-and-effect chains. Logic models attempt to capture such pathways by making (a) such pathways explicit through input-process-output chains as well as appropriate feedback loops; and (b) by identifying how the inputs, process, outputs and impacts in the theory of change will be measured empirically (through the identification of appropriate indicators categories and indicators).

The stylised, flow-chart Logic model represented in **Figure 6** captures the main elements of a ToC that is applicable to a NSI or STI system. The red box in this graph contains the various desired policy-related 'outputs', as well as derivate 'outcomes' and 'impacts' in wider society. When used as an analytical model, it must be populated with empirical information and performance indicators that operationalise (causal) linkages and flows between the various modules of the model in concrete and observable terms. These indicators guide and facilitate information gathering and - if possible - measurement. Note that although the main causal structure of this Logic model is a 'linear process' with flows from inputs and impacts, it is also a non-linear 'circular' structure, with feedback loops and bi-directional connections between the various components.

Such a Logic model enables systems-level process-related interpretations of both policy objectives and policy outcomes, in terms of performance indicators within specific dimensions, but also general achievements such as 'efficiency' and 'alignment'. In brief, this particular visualisation shows:

- That problems, needs and challenges arise within society, or the economy or the environment which are typically identified and targeted in national policies (such as in the South African White paper on STI) and programmes;
- The 'logic of programmes' are clearly captured in the middle block: (intervention) programmes typically have objectives, produce outputs (through the implementation of various activities) which ultimately results in outcomes (short-and medium-term) and impacts;
- The arrows below the middle block identifies standard evaluation criteria (relevance, effectiveness, alignment, efficiency and utility and durability) as these apply to different relationships between different components of interventions.

Figure 6: Example of a systems-level Logic model



Source: Adapted from Jonkers et al. (2018)

Following the terminology of this Logic model, our M&E framework applies the same set of key terms, including 'output', 'outcome', 'results' and 'impact'. We use this terminology according to standard practice - both in the academic discipline of evaluation as well as many official policy documents. The standard usage of these key concepts is as follows:

- Inputs typically refer to those factors (usually related to investment or funding, human resources and material infrastructure and equipment) that are required to perform the required activities in interventions and programmes.
- Outputs are end-products or deliverables of programme or intervention activities. Stated differently: they are the typical goods and services that are produced or delivered (hence "deliverable') to the target group. These can be tangible goods such as materials, manuals, ICT devices, equipment, etc. or more intangible services such as technical support, consultations, and training workshops and so on.
- Outcomes are immediate changes that we wish to bring about through our interventions. The terms 'gains' or 'benefits' are often as synonyms for outcomes. An outcome always presupposes that some change (in behaviour, attitude, values, beliefs, competencies, knowledge, awareness, commitment, etc.) has occurred if an intervention is deemed to be successful. Outcomes are typically separated into immediate or short-term (or proximate) outcomes and medium-term (or distal) outcomes.
- Impacts are often seen as the long-term accumulated 'ultimate' outcomes. The term 'results' is sometimes used as synonym for impact.

3.3 Applying ToCs and Logic models: the NRDS and the TYIP

To illustrate how a TBE-approach, including ToCs and Logic models, have been applied to the SA STI-domain at the systems level, we selected two key documents: The National Research and Development Strategy (NRDS, 2002), and the Ten-Year Innovation Plan (TYP, 2008). In both documents we found more or less explicit ToCs and associated Logic models.

The central structural concept in South Africa's National Research and Development Strategy is that of the National System of Innovation. By adopting NSI 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' are proposed, that in contemporary terminology might be regarded as areas of impact for the NSI, namely:

- quality of life;
- growth and wealth creation.

Thereafter, the NRDS strategy outlines three key 'processes' that serve the goals, and which might approximate to outcomes in today's language, these being:

- business performance;
- technical progress (innovation and improvement);
- effective and growing SET human capital.

These 'intermediate processes' or outcomes are 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;
- future R&D capacity.

Where **Figure 7** shows the most important relationships in the ToC of the NRDS, the diagram in **Figure 8** presents the NRDS depiction where key outcomes in the ToC are linked to performance indicators. Although not all the elements or indicators are covered, the structure in both ToCs starts to approximate a Logic model of causal relationships and connections between systems components, outcomes and impacts.

Figure 7: Theory of Change for the National Research and Development Strategy

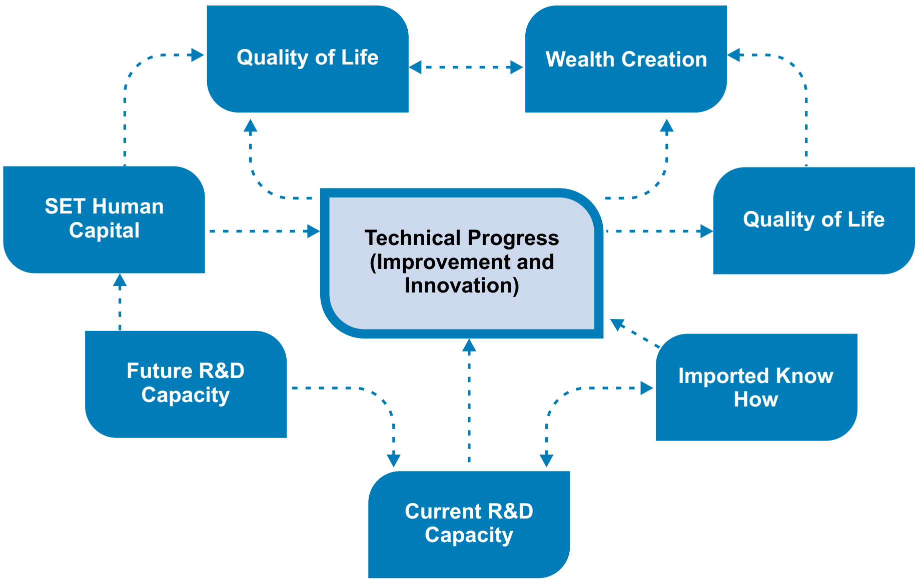
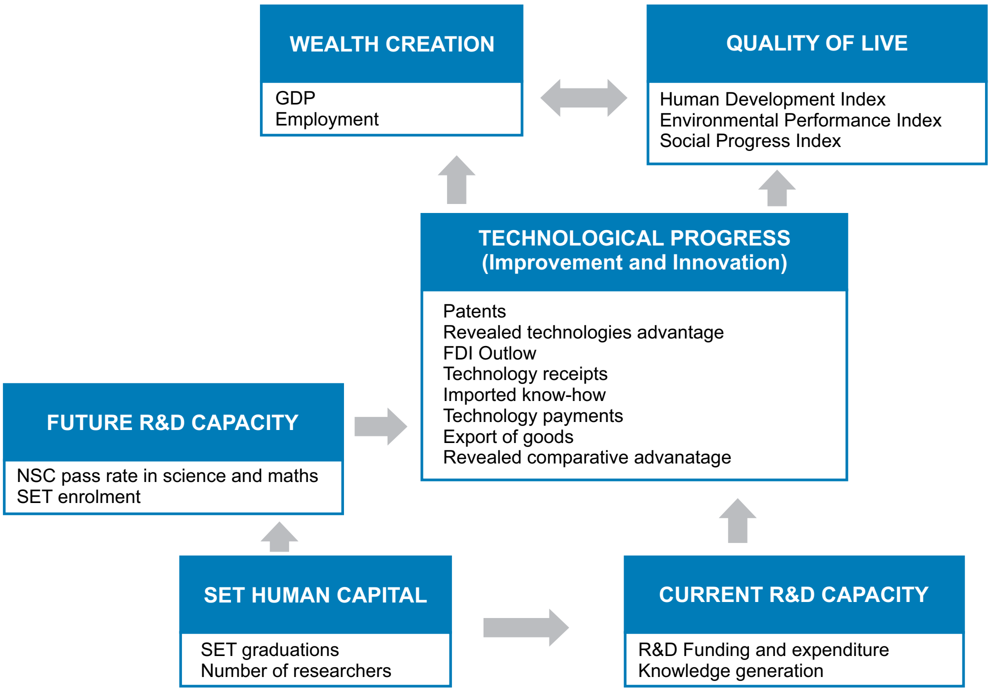


Figure 8: Logic model for the National Research and Development Strategy



Explaining the relationship between these three layers of concepts in the ToC, the 'logical indicator framework' can be read as a 'draft' ToC, which is based on the premise that modern economies require all these elements to be present and growing. The two major outcomes expected from R&D and innovation are increased wealth and quality of life. In developed countries, more than 50% of economic growth is attributable to technical progress and innovation. 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 in 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 innovative products, processes and services).

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

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

It is clear from the above ToC and supporting narrative that the investment in R&D should have been explicitly included in the diagram (at the bottom). The (reconstructed) ToC would then read as follows:

- **IF** a country invests sufficient funds in R&D … **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 technological innovation and growth, … **THEN** more wealth will be created by SA businesses and enterprises ... **AND** the quality of life of South Africans will improve.

The Ten-Year Innovation Plan (TYIP, 2008), 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 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."* (TYIP, 2008; p. vii). It is this analysis that informs the central tenets of the plan that (i) the gap needs to be closed, and (ii) *"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"* (TYIP, 2008; p. vii).

After a discussion of the general relationship between research output, innovation, and socio-economic development, TYIP's strategy introduces five grand challenges, in which specific advantage is seen to lie for South Africa, and – especially – for its transition to a knowledge-based economy. In other words, it appears that the grand challenges are seen as a proxy for the knowledge economy in South Africa. 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, South Africa would move in the direction of a knowledge economy.

TYIP's conceptual framework is graphically depicted in **Figure 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 from our discussion of the NRDS above. The TYIP does not make any explicit reference to the two main impact domains that formed the core of the NRDS, viz. wealth creation and quality of life. Instead, the focus has shifted towards a different overarching goal: to become a (competitive) knowledge economy. This is captured clearly on page vii of the Plan: "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". The Executive Summary of the Plan continues to argue that there are *"four drivers of progress toward a knowledge-based economy"*, namely:

- Human capital development;
- Knowledge generation and exploitation (R&D);
- Knowledge infrastructure;
- Enablers to address the 'innovation chasm' between research results and socioeconomic outcomes.

Figure 9: Grand challenges and enablers of the Ten-Year Innovation Plan

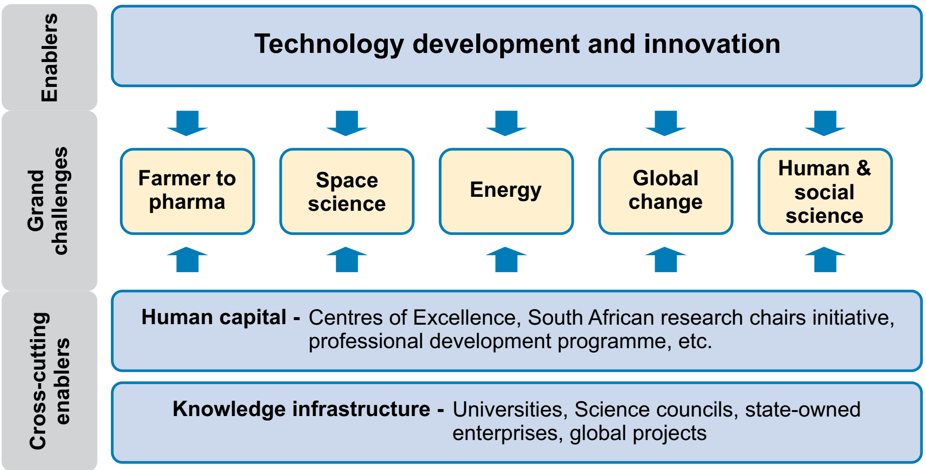


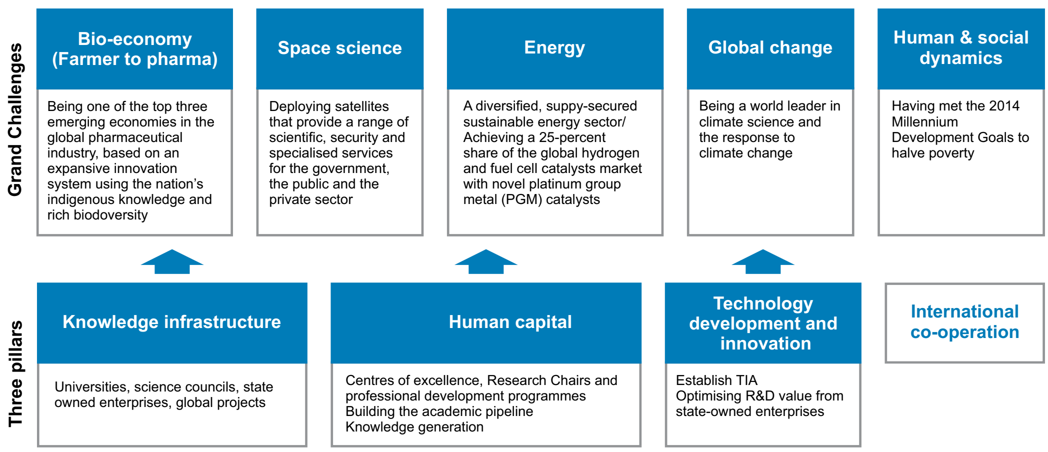
Figure 3: Grand challenges and enblers of the ten-year plan

Unfortunately, a few pages later, TYIP (2008) puts forward a different argument. It reiterates that *"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"*. And it continues by stating that the knowledge-based economy rests on four pillars: innovation, economic and institutional infrastructure, information infrastructure and education. These statements are quickly 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"*. Instead *"this Ten-Year Innovation Plan has a different starting point: 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"*. Here we find that the five grand challenges are indeed seen as the major outcome or impact areas of the TYIP. In order to achieve these major outcomes, three 'pillars' or 'drivers' are subsequently identified and elaborated upon:

- Knowledge infrastructure;
- Human capital (development);
- Technology development and innovation.

On the basis of this narrative, we have attempted to construct a ToC for the TYIP, which is shown in **Figure 10**.

Figure 10: Theory of Change for Ten-Year Innovation Plan



There is no dedicated discussion in the TYIP of specific strategic objectives, though there are many references to the plan's objectives or purposes embedded in the narrative. At the highest level, the Foreword by the DG (TYIP, 2008; p.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."* Later it is stated that the 'purpose' of the TYIP is "to help drive South Africa's transformation towards a knowledge-based economy", which in turn will be 'driven' by the four elements (drivers) mentioned above. In the absence of any explicit statement to the contrary, optimising each of these four 'elements' can be seen as the implicit strategic objectives of the Plan, with the five grand challenges constituting a programmatic intervention in support of the above four objectives, and not an objective in itself.

The TYIP provides a more comprehensive and quantitative framework for monitoring progress than the NRDS. For each of the five grand challenges a set of 'outcomes' is stipulated, which can be thought of as impact or outcome indicators and/or system-level performance benchmarks (as opposed to targets); these have largely been formulated or selected in such a way that they allow ready international comparison, and most of them constitute part of the statistical indicators developed countries and emerging economies would routinely collect. In addition, the strategy lists an additional set of macro-level metrics through which South Africa's transformation toward a knowledge-based economy may be monitored; these indicators are listed in Figure 11, a table lifted from page 8 of the TYIP 2018 report.

Figure 11: TYIP performance indicators and performance measures

Indicators	Measure	2018
SA positioned as knowledge-based economy	Economic growth attributable to technical progress (10% in 2002)	30%
	National income derived from knowledge-based industries	>50%
	Proportion of workforce employed in knowledge-based jobs	>50%
	Proportion of firms using technology to innovate	>50%
	GERD/GDP (0.92 in 2005; short-term 2008 target was 1%)	2%
	Global share of research outputs (0.5% in 2002)	1%
	High- and medium-tech exports/services as a percentage of all exports/services (30% in 2002)	55%
	Number of South African-originated US patents (100 in 2002)	250
Research and technology enablers	Matriculates with university exemption in maths and science (5.2% maths and 5.9% science in 2005)	10%
	SET graduates as percentage of all students in public higher education institutions (28% in 2005)	35%
	Number of SET PhD graduates [er year (561 in 2005)	3 000
	Number of full-time equivalent researchers (was 11 439 in 2005)	20 000
	FTE researchers per 1 000 workforce employed (1.5 in 2005)	2.6

These two examples from SA M&E practices – the National Research and Development Strategy and the Ten-Year Innovation Plan - both underscore the critical importance of an adequate articulation of STI policies, designing the appropriate ToC, and getting the ToC right in terms of implementation into Logic models and performance indicators. The ToC and Logic models of NRDS and TYIP tend to emphasize government policies that are designed to shape, support and drive components of the NSI and STI system.

In conclusion: we have argued in this section that any proposed M&E framework for the South African STI or NSI system needs to be theory-based. In practice it means that the monitoring and evaluation questions that populate the framework needs to be embedded in some higher-order conceptual tool or theory of change that guides and explains the inclusion of such questions. Before we discuss in some detail the monitoring and evaluation components of the proposed framework, we need to pause and briefly discuss how we perceive and define the South African STI system in this report. The next section provides necessary background information on the 'National System of Innovation' model and its core concept: 'innovation'.

Section 4

The STI system and the NSI

A country's STI system is defined as the set of functioning institutions, organisations and policies, which relate and *"interact in the production, diffusion and use of new, and economically useful, knowledge"* that ensures the pursuit of a common set of socio-economic goals and objective (Godin, 2007: p. 7). Such a system is highly complex and very dynamic, where links between causes and effects are often extremely difficult to determine. A comprehensive M&E framework will have to address many STI system components - from small, dedicated initiatives in the business sector to large-scale government programmes. The framework will need to include the connections between components, which are essential 'make or break' elements in such systems.

Embarking on a trajectory towards an M&E framework, there are a number of key concepts and terms that require clarification. One of the most elusive are the notions of 'quality' or 'excellence'. Another example is the notion of 'relevance' – a dimension that clearly requires more qualitative judgments by experts in different fields. The same also applies to attempts to measure the 'social' and 'economic impact' of science and technology. Another core concept, 'innovation', deserves special attention because it has been one of the major driving forces of STI policies during the last few decades in all advanced economies worldwide. Although the core concept of 'innovation' is widely used, and with varying meanings, it is nonetheless fairly well-defined for statistical data gathering – **see Box 2** – and designed for M&E type applications. Our view of the STI system builds on the very familiar 'National System of Innovation' (NSI) model, which has been applied for several decades in SA policy settings.

NSI captures the interactions, relationships and linkages of system components at the different levels. The NSI can be viewed as a larger system into which the STI system feeds. Out of the various NSI variants available, we select the model developed and described by Kuhlmann and Arnold[4]. Their framing of the NSI comprises of three dimensions: the demand environment; framework conditions and the research and innovation performers.

Focussing on innovation, for the success of a new product or service in the market, the M&E framework will need to fully incorporate the business sector side of the STI system. Opportunities for R&D-intensive business development, manufacturing production capabilities, incentives to enhance competitiveness, the available pool of skilled personnel, and many other issues, all become critical in the value chain that leads from education and knowledge creation to economic growth. A successful STI system must have these components in place, and they should therefore be accounted for in an M&E framework.

Box 2. Defining 'innovation'

The 'Oslo Manual', an international reference guide developed by the OECD and European Commission which is applied by statistical offices worldwide, describes the concept 'innovation' as follows:

"An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (EC/OECD, 2018; p. 21)

… where the generic term 'unit' in this definition applies to any 'actor' responsible for an innovation – either an institutional or organisational unit (in any sector of the economy), a household or an individual.

Following the Oslo Manual definition, it is therefore important to emphasise that the notion of 'innovation' refers to applications of something new in a user environment – it is NOT about creative ideas, breakthrough inventions developed in a university laboratory, or brilliant business strategies. Slightly rephrased: *"innovation occurs when a novel product, service, design or approach finds its way into the workplace, market or society".*

[4] *Kuhlmann, S. and Arnold, E. (2001) RCN in the Norwegian research and innovation system. https://ris.utwente.nl/ws/files/15070352/RCN_in_the_Norwegian_Research_and_Innovation_Syste_1_.pdf*

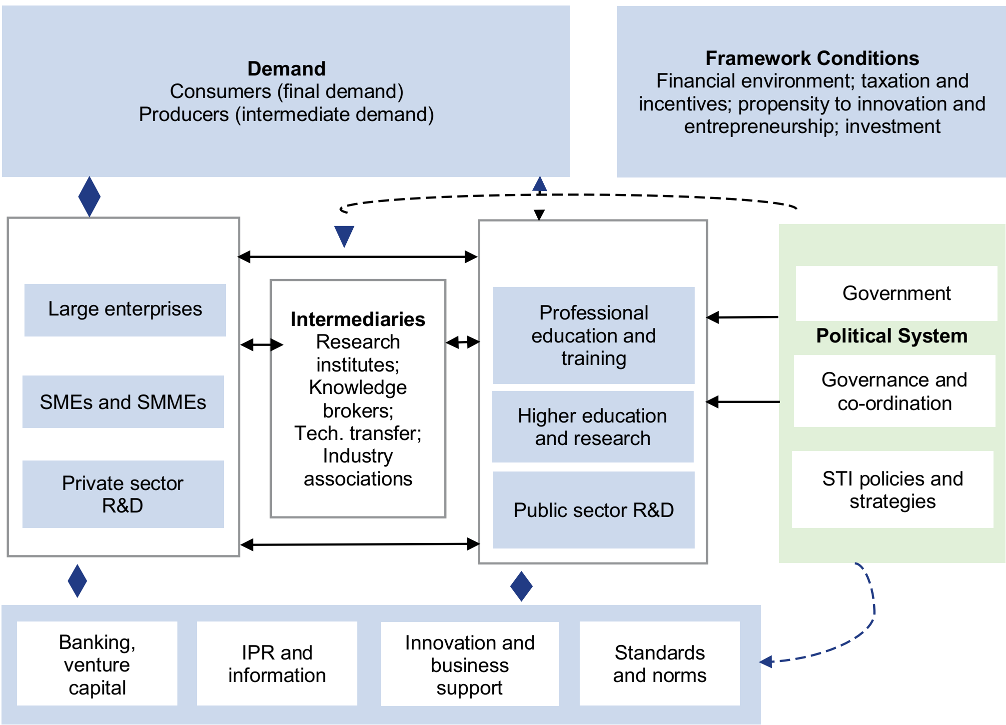
This fairly broad definition encompasses different operationalisations of innovation activities and associated classes of innovation, such as 'open innovation', 'inclusive innovation' and 'social innovation'.[5]

Although the M&E framework focuses on the STI system, the notion of innovation should not exclude domains such as 'innovation for policy-making' or the impact of science on policy-making. Innovation can take place in many contexts, including government and educational institutions – even the NSI itself.

Many issues and questions that are covered in the Oslo Manual for measuring innovation in the business sector can also be applied, with some modifications, to the public sector. However, public sector innovation surveys will have to comply with another set of policy needs and evaluation criteria that require collecting additional information and other types of data (Arundel et al., 2018).[6]

Adapting Kuhlmann and Arnold's NSI model to M&E framework setting, as depicted in **Figure 12**, includes a stronger focus on education, research and science, as well as the importance of intermediate organisations (both public and private) between the Education and Research sector and Business sector. The model highlights three main elements that are linked to the STI performance dimensions of the system. First, elements related to the performance of the main 'institutional blocks'. Second, elements linked to 'connectivity within the system'; and third, knowledge and capabilities.[7] Arnold (2004) further argues that the framework conditions (financial environment, taxation and incentives) within which the institutions operate and interact shape the performance of a system.

Figure 12: Diagram of the National Innovation System structure



Source: adapted from Kuhlmann & Arnold, 2001

This particular 'lens' on the NSI structure is clearly geared towards innovation from a business sector perspective, not the broader socio-economic context or the broader notion of 'innovation' (**see Box 1**). The overview therefore omits government innovation and service delivery directly to the general population where citizens are defined as 'consumers' within 'supply/demand' relationships. Embracing a broader socio-economic perspective, the M&E-oriented version of this diagram (see **Figure 17 in section 6**) replaces 'Demand'

[5] *The Oslo Manual itself further operationalises 'innovation' with a strong focus on the business sector and firms, where 'business innovation' activities are defined in terms of: "Innovation activities include all developmental, financial and commercial activities undertaken by a firm that are intended to result in an innovation for the firm" and "A business innovation is a new or improved product or business process (or combination thereof) that differs significantly from the firm's previous products or business processes and that has been introduced on the market or brought into use by the firm." Source: OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg (https://doi.org/10.1787/9789264304604-en)*

[6] *Arundel, A., Bloch, C. and Ferguson, B. (2019). Advancing innovation in the public sector: aligning innovation measurement with policy goals, Research Policy, 48 (3), 789-798.*

[7] *Arnold, Erik (2004) Evaluating research and innovation policy: A systems world needs systems evaluations. Research Evaluation, vol. 13(1). According to Arnold (2012), (Understanding long-term impacts of R&D funding: The EU framework Programme; Research Evaluation, vol. 21) the NSI framework perspective has important implications for understanding STI performance. Arnold notes that "bounded rationality of actors" in the system has a significant effect on its performance. Godin (2009) notes that, what is important to the overall performance of the system is not largely dependent on how the individual institutions perform but rather the interactions with each other. The other elements to consider include capacity and quality of research and education; strategic or managerial performance; and the effectiveness of interacting with other dimensions of the STI system.*

by the more appropriate heading 'Inclusive and Sustainable Development' which captures underrepresented features of the NSI such as social innovation, inclusive innovation and broader benefits of STI to SA society and economy.

It is also important to emphasise that public sector or private sector R&D only accounts for a minor share of innovation performance in knowledge-intensive business sectors. More important contributors are demand factors (consumers, producers), education (availability of highly qualified and skilled graduates) and other political and economic framework conditions that shape and drive job creation, entrepreneurship and economic growth. Targeted public sector investments and incentive systems are needed to spur business sector innovation and improve the NSI's general performance.

It is evident that prior M&E studies in South Africa have given relatively little attention to interactions and linkages between the various players in the NSI, especially those that are not related to government institutions. Gathering standardised and reliable information and data on such interactions and linkages remains a big challenge for anyone working in this field. We discuss, in the following section, this issue in more detail and also why it should be a top priority for future work in this area. Moreover, in the open South Africa economy and society, many components of the STI system connect to the rest of the world through linkages, interactions and flows that involve actors and partners outside the national border.

In addition, Arnold (2004: p. 6) states, another key perspective to consider when evaluating a […] system is the 'historical path dependence' of the institutions in the system. Decisions made earlier and how the institutions could perform previously and the learning processes that have happened influence the current and future performance of the system. In Arnold's model of the NSI, research institutions and their environments are inter-dependent. In essence, the different actors in the system do not work autonomously, that is, "the performance of the individual firm or institution and the system as a whole are inter-related" (Arnold, 2004: p. 5).

Section 5

Monitoring

5.1 Which indicators do we need?

This section is devoted to a discussion and articulation of the monitoring component of the proposed M&E framework. As is traditionally the case, our focus will be on metrics-based indicators and composite indicators. These are the quantitative and statistical building blocks of evaluation methodologies. Whereas evaluation is targeted to *'how, why, where* and *who'* questions, monitoring is more focused on the time-dependent *'how much'*, *'to what extent'* and 'how fast 'questions. To arrive at evidence-based judgments, evaluation addresses specific systems, policy and strategic objectives - such as productivity, effectiveness, efficiency, inclusivity, diversity, relevance and sustainability - and is supported by a wide spectrum of background and foreground information as well as selected indicators. These indicators can be either 'quantitative' (based on measurement and statistics), or 'qualitative' (extracting their information from sources such as interviews or case studies).

Ideally, a well-designed selection of indicators should serve several M&E purposes simultaneously:

- monitor how successful a 'unit' or 'entity' within the SA STI system is (or has been) at reaching pre-determined goals;
- an effective means to measure progress and scientific strengths (and weaknesses), and to report on results of reviews and evaluation;
- working backwards from a desired end target position that relates to our objectives and reasonable expectations;
- compare and benchmark the performance of different units/entities.

In order to select the most appropriate candidates for such portfolio, each proposed indicator should meet the following quality criteria:

- fairness - degree to which it accommodates key traits and characteristics (specific for country, region, organisation);
- added value - extent to which the indicator introduces a new perspective;
- transparency - extent to which the data, or data processing, can be independently verified;
- independence - extent to which the data is resistant to external manipulation;
- cost-effectiveness - costs to obtain the required data, and the expected compliance cost to institutions and government, related to perceived benefits;
- behavioural impact - likely effects on the practice of universities or their organisational subunits, and whether that impact is in line with desired managerial or policy outcomes.

These quality criteria are especially important in the case of policy-relevant 'key performance indicators' (KPIs) that are designed to compare or monitor the performance of different units/entities over time. When considered for this purpose, each proposed indicator should be critically assessed in terms of:

- Information value - reduce complexity and extract meaningful information;
- Operational value - acceptable concepts, definitions and criteria;
- Analytical value - accurate data, measurements and performance indicators;
- Monitoring and evaluation value - relevant information and knowledge for users;
- Stakeholder value - credibility among stakeholders and public confidence.

Meeting all these requirements simultaneously is impossible: compromises and 'next best' solutions are inevitable. The most practical way to reach such a solution is to build on current 'good practices' by using the most recently available indicator-based documents on the SA STI system as a point of departure. These documents present generally accepted analytical models of the SA STI system and associated views of systems-level performance. The methodological challenge is to integrate these documents into a single, overarching indicator-based model and a generally acceptable viewpoint.

Depending on the available information, level of ambition, and its strategic focus, the general format of the 'M Framework' could be either 'broad' (systems-level comprehensive), in-depth (focussed on specific high-priority elements of the system), or a combination of both. Many (supra) national STI indicators reports, like the NACI-produced *South African Science Technology and Innovation Indicators Report,* tend to select the third option and strike a balance between breadth and depth. The recent SciSTIP-report for the NRF on "The state of the South African research enterprise" presents a systems-level, indicator-driven approach that combines a broad overview with in-depth information of the research system.[8]

STI indicators come in all kinds of shapes and purposes. There are many classification systems and categories. Although indicators can also be based on qualitative data (e.g. survey responses that are aggregated), most indicators in STI monitoring frameworks are 'quantitative' in nature (numbers, ratios, rates, etc.). The quantitative indicators comprise 'statistical indicators' (numerical data) but also 'categorical indicators' (yes/no or 0/1 data). Another basic categorisation is the distinction between 'summative indicators' (background information on context and outcome mapping) and 'formative indicators' (performance monitoring). Depending on the robustness or validity of the information ('hard' or 'soft') captured by an indicator, or its analytical value, it could be regarded as a 'strong indicator' or 'weak indicator'. Another difference concerns 'lag indicators' (retrospective view) and 'lead indicators' (prospective view). Finally, there is the important subset of 'key performance indicators' (usually these KPIs refer to issues with the highest level of policy relevance, and are indicators selected by major stakeholders).

The next sub-section presents a general overview of the quantitative/statistical/lagging indicators mentioned in the White Paper (2019) and a few selected other sources. In line with the system-level perspective of the proposed M&E framework, our overview and review of STI indicators is focussed on indicator categories, not individual indicators. Our goal is to present those classes of indicators that capture key features of the STI system. The different types of 'innovation indicators' that are mentioned go beyond those of the Oslo, in so far as they may also refer to innovations outside the business sector, such as for example social innovations in civic society, science-based innovations produced by universities, or teaching innovation created elsewhere in the education sector.

5.2 Scoreboards and indicators: the process

For the purposes of this study, we have followed a two-pronged approach (done concurrently) in the development of a proposed South African STI Scoreboard. The first phase - a more deductive approach - was to review the major international STI indicator frameworks, indices and scoreboards. The second one – a more inductive approach - was to review a large number of other documents (reports and academic studies) which made reference to specific STI indicators in order to generate as comprehensive a list of relevant indicators as possible. The outcome of the first approach was a decision to adopt the European Innovation Scoreboard as the first point of departure for the proposed SA STI Scoreboard (and Index); the outcome of the second approach, was the construction of a comprehensive 'STI Indicator Bank' at CREST.

5.2.1 Review of existing scoreboards

At our M&E expert workshop in March 2019 (see subsection 1.1), the team decided to adopt the main dimensions and categories that are embedded in the 'European Innovation Scoreboard' (EIS) as a general heuristic framework and general point of departure for the proposed South African STI Scoreboard. The team was of the opinion that this Scoreboard meets most of the criteria for such a scoreboard – being balanced, comprehensive and clear with 16 high-level indicators covering higher education, science, technology and

[8] *Johann Mouton, Isabel Basson, Jaco Blanckenberg, Nelius Boshoff, Heidi Prozesky, Herman Redelinghuys, Rein Treptow, Milandré van Lill and Marthie van Niekerk (2019), The state of the South African research enterprise, SciSTIP report for National Research Foundation (http://www0.sun.ac.za/scistip/wp-content/uploads/2019/08/state-of-the-South-African-research-enterprise.pdf)*

innovation. In addition, three other considerations played a role in this decision. First, although this scoreboard is funded by the European Commission and hence is focused on indicator-based comparisons of European Union member states, it also includes a number of non-European countries for reasons of international benchmarking - South Africa is one of those. Second, the most recent NACI Indicator reports are also framed within the broad parameters of the EIS. And finally, this scoreboard also includes a single-number 'composite indicator' (or 'index') to categorise the European countries according to their overall innovation performance. The advantage is that this allows for relatively easy comparison and benchmarking across different countries.[9]

However, it is worth pointing out that the EIS changed in recent years and more specifically it made quite substantial changes to its measurement framework (and therefore also of its main indicators). These changes are illustrated in Figure 13, followed by two tables (Tables 2 and 3) which compares the two measurement frameworks.

Figure 13: Changing measurement frameworks in European Innovation Scoreboards

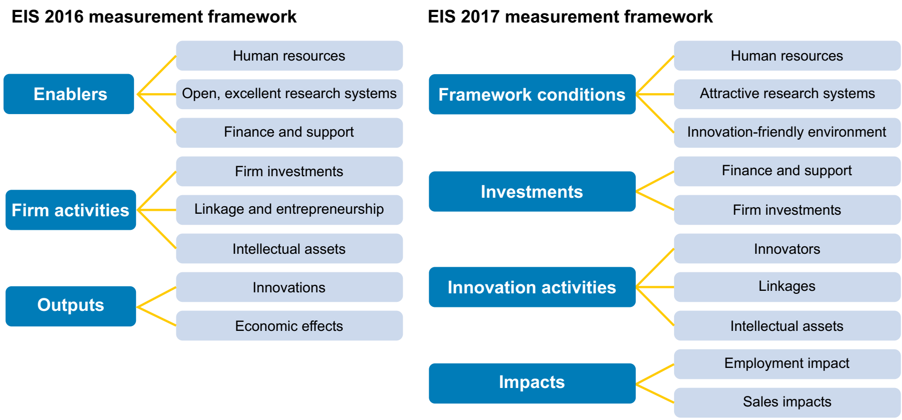


Table 2: Measurement Framework of the European Innovation Scoreboard (2016 version)[10]

HUMAN RESOURCES
1.1.1 New doctorate graduates 1.1.2 Population aged 30-34 with tertiary education 1.1.3 Youth with at least upper secondary education
OPEN, EXCELLENT RESEARCH SYSTEMS
1.2.1 International scientific co-publications 1.2.2 Top 10% most cited publications 1.2.3 Non-EU doctorate students
FINANCE AND SUPPORT
1.3.1 R&D expenditure in the public sector 1.3.2 Venture capital expenditures
FIRM INVESTMENTS
2.1.1 R&D expenditure in the business sector 2.1.2 Non-R&D innovation expenditures
LINKAGES AND ENTREPRENEURSHIP
2.2.1 SMEs innovating in-house 2.2.2 Innovative SMEs collaborating with others 2.2.3 Public-private co-publications
INTELLECTUAL ASSETS
2.3.1 PCT patent applications 2.3.2 PCT patent applications in societal challenges 2.3.3 Trademarks applications 2.3.4 Design applications

9 The Oslo Manual (EC/OECD, 2018; p. 2020) states: "Composite indexes provide a number of advantages as well as challenges over simple indicators […]. The main advantages are a reduction in the number of indicators and simplicity, both of which are desirable attributes that facilitate communication with a wider user base (i.e. policy makers, media, and citizens). The disadvantages of composite indexes are as follows:

- *With few exceptions, the theoretical basis for a composite index is limited. This can result in problematic combinations of indicators, such as indicators for inputs and outputs.*
- *Only the aggregate covariance structure of underlying indicators can be used to build the composite index, if used at all.*
- *The relative importance or weighting of different indicators is often dependent on the subjective views of those constructing the composite index. Factors that are minor contributors to innovation can be given as much weight as major ones.*
- *Aside from basic normalisation, structural differences between countries are seldom taken into account when calculating composite performance indexes.*
- *Aggregation results in a loss of detail, which can hide potential weaknesses and increase the difficulty in identifying remedial action.*

10 Indicators in RED were deleted in the revised version; Indicators in BLUE were changed in the revised version

INNOVATORS
3.1.1 SMEs with product or process innovations 3.1.2 SMEs with marketing or organisational innovations 3.1.3 Employment fast-growing enterprises of innovative sectors
ECONOMIC EFFECTS
3.2.1 Employment in knowledge-intensive activities 3.2.2 Medium and high-tech product exports 3.2.3 Knowledge-intensive services exports 3.2.4 Sales of new-to-market and new-to-firm product innovations 3.2.5 License and patent revenues from abroad

Table 3: Measurement Framework of the European Innovation Scoreboard (2017 revised version)[11]

FRAMEWORK CONDITIONS			INNOVATION ACTIVITIES	
Human resources			**Innovators**	
1.1.1	New doctorate graduates		3.1.1	SMEs with product or process innovations
1.1.2	Population aged 25-34 with tertiary education		3.1.2	SMEs with marketing or organisational innovations
1.1.3	Lifelong learning		3.1.3	SMEs innovating in-house
Attractive research systems			**Linkages**	
1.2.1	International scientific co-publications		3.2.1	Innovative SMEs collaborating with others
1.2.2	Top 10% most cited publications		3.2.2	Public-private co-publications
1.2.3	Foreign doctorate students		3.2.3	Private co-funding of public R&D expenditures
Innovation-friendly environment			**Intellectual assets**	
1.3.1	Broadband penetration		3.3.1	PCT patent applications
1.3.2	Opportunity-driven entrepreneurship		3.3.2	Trademark applications
			3.3.3	Design applications
INVESTMENTS			**IMPACTS**	
Finance and support			**Employment impacts**	
2.1.1	R&D expenditure in the public sector		4.1.1	Employment in knowledge-intensive activities
2.1.2	Venture capital expenditures		4.1.2	Employment in fast-growing enterprises of innovative sectors
Firm investments			**Sales impacts**	
2.2.1	R&D expenditure in the business sector		4.2.1	Medium and high-tech product exports
2.2.2	Non-R&D innovation expenditure		4.2.2	Knowledge-intensive services exports
2.2.3	Enterprises providing training to develop or upgrade ICT skills of their personnel		4.2.3	Sales of new-to-market and new-to-firm product innovations

Source: European Commission (2019)

The 2016 version of the EIS measurement framework conforms more to standard analytical dimensions found in STI scoreboards - with the distinctions between enablers, activities and outputs. The revisions made in 2017 were clearly informed by a perspective from the side of business enterprises and innovators and their performance. A good example of this is the fact that 'human resources' and 'an attractive research system' are included under

[11] *Indicators in GREEN are new indicators (compared to the 2016 version); indicators in BLUE are changed indicators*

the heading of 'framework conditions' which are seemingly seen as feeding into the next two big categories of investment and innovation activities. Conversely, making 'impacts' a separate category in the revised framework is a clear improvement.

Hence, although we take the EIS as the point of departure for the SA STI Scoreboard, we would argue that the EIS has two 'weaknesses': (1) 'upstream' domains of science and knowledge production remain under-represented in the revised measurement framework; (2) some of the selected indicators within the sub-dimensions should be augmented by existing (standard) indicators. As far as the former is concerned, the emphasis in an innovation scoreboard towards business, innovation and economic indicators is not surprising in an 'innovation scoreboard'. Our brief, however, is to develop an STI scoreboard that covers both 'upstream' (science, R&D, knowledge production) and 'downstream' features (technology, innovation and socio-economic impact). As to the latter point, there are numerous cases in the current scoreboard where a particular sub-dimension (e.g. human resources) can be strengthened through the inclusion of additional indicators (e.g. number of doctoral graduates per million of the population). In social measurement it is generally assumed that at least three to five indicators are required to adequately capture the meaning of a construct. In general, we believe that the measurement framework needs to be strengthened by the inclusion of additional indicators (and in some cases traditional standard indicators). We have thus subsequently included additional analytical dimensions and indicator categories in our proposed framework to address these 'weaknesses' in the EIS.

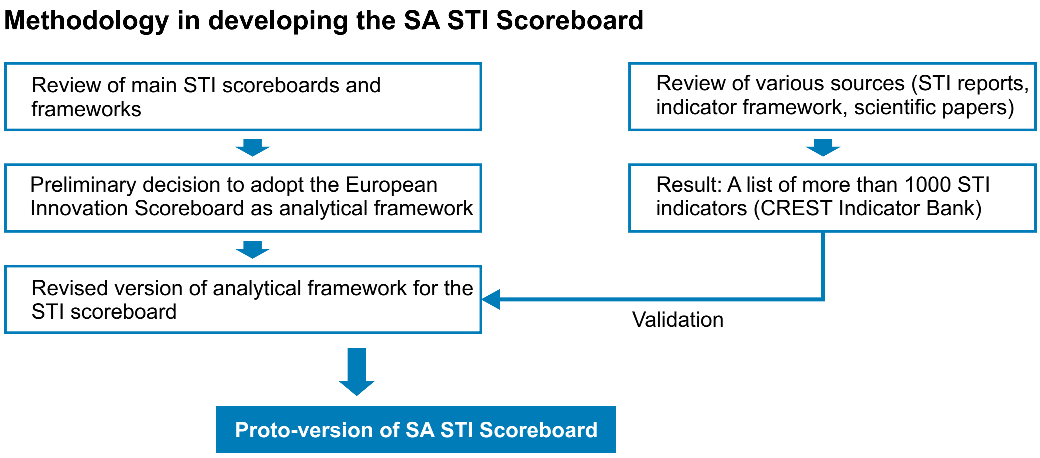
5.2.2 Review of STI indicators and development of an inventory

In addition to a review of existing scoreboards and indicator frameworks, we also reviewed a large number (more than 50) of reports (including STI Indicator reports, science and innovation reports, academic studies, and so on) in order to produce a comprehensive inventory or bank of currently available STI indicators. By way of illustration we list some of the main reports that we included in this second approach: *UNESCO Science Report, African Innovation Outlook, the most recent NACI Indicator reports, the most recent NSF Science and Engineering Indicator Reports, the CHINA STI Outlook report, the Technology Achievement Index and the report on Indicators of Technological Innovation in Latin America and Caribbean Countries.* As part of this second approach we also worked through the current *White Paper on Science, Technology and Innovation* which mentions several STI-related indicators or statistics (on pages 30, 31, 32, 36, 39, 44, 45, 46, 47, 62, 64, 65). And finally, CREST has recently produced a comprehensive report on the state of *the South African research enterprise* which contains 84 indicators (some of them new indicators). The indicators were also added to our inventory.

The main purpose of this second approach was to enable us to check and validate the results of the first process. The combination of the more deductive (top-down) approach, which reviewed the main existing scoreboards, with the more inductive (bottom-up) approach, which identified and listed individual indicators, enhanced the final product. It is important to realize that many of the existing internationally administered scoreboards use a relatively small set of datasets as sources for their indicators (Eurostat, OECD, UNESCO, World Bank, Patent databases, CIS, UIS, etc.). The advantage of this is self-evident – it allows for comparative analyses over time and across countries. However, at the same time, there is ongoing scholarships by STI scholars who conduct more country and domain specific studies and identify potentially useful and novel indicators. These indicators are as yet not standardised and therefore do not typically get incorporated in the major frameworks. They are however useful and deserving of our attention. This is particularly true for those STI domains where there is a dearth of standard indicators, including measures for knowledge flows and linkages across the national system of innovation.

Our approach in developing the proto-framework for the scoreboard is illustrated in **Figure 14** below.

Figure 14: Methodology in developing the proto-framework of the SA STI scoreboard



5.3 Proto-framework of the SA STI Scoreboard

How to assemble all these indicators in order to assess their relevance for the M&E framework? High-quality M&E frameworks require a logical structure, internal consistency, clarity, purpose and comprehensiveness in coverage. As for structure, the large multitude of possible indicators requires meaningful ordering principles that apply to the entire indicator framework. With regards to internal consistency, clarity and purpose, we organised the high-level categorisation of possible indicators according to two principles: (1) **'Analytical scope'** – the system dimension (or component) addressed by the indicator; (2) **'Functional objective'** - the purpose the indicator must perform.

As far as 'functionality' is concerned there are many possibilities to consider and implement (see discussion in **Section 2**) - here we assign each indicator, mainly for illustrative reasons, to a category according to the main geographical perspective of the monitoring exercise:

- Domestic benchmarking (within-SA comparisons and trends) ;
- International benchmarking (country-level comparisons and trends).

The overarching analytical framework is that of the Logic model, as discussed in **Section 3**, as well as the learnings taken from the European Innovation Scorecard. Here we distinguish between the following four 'main system-level dimensions' of the proposed scoreboard:

- Inputs and enablers (tangible investments, human capabilities and infrastructures);
- Flows and linkages (collaborations, networks and connectivity);
- Outputs (tangible scientific, technological and innovation products);
- Outcomes and impacts (socio-economic and developmental outcomes and benefits).

The framework in **Table 5** disaggregates these analytical dimensions into three further levels of increasing disaggregation:

1. Analytical dimension Level 1 (Sub-dimension)
2. Analytical dimension Level 2 (Sub-dimension or sub-domain)
3. Analytical dimension Level 3 (Indicator category)

The framework does not contain the actual indicators per category, nor the data sources. This information is currently being cleaned and updated in the CREST Indicator Bank referred to above.

Adopting the Logic model and a derivate classification system of STI indicator categories, **Table 4** provides a preliminary, non-exhaustive outline (or template) of a possible SA STI Scoreboard. Naturally, this indicator-oriented framework imposes a very simplified structure onto an extremely complexity STI system. Any kind of scoreboard is by definition an information reduction tool that can only reflect some elements of the STI system. Hopefully those elements are carefully selected and considered of high relevance by major stakeholders of the system. Its composition, in terms of including all relevant systems components, and the choice of indicators, are two crucial parameters that 'make or break' the applicability of the scoreboard.

In the framework below (**Table 5**) we have provisionally indicated where we believe data for a specific benchmarking function is available (√) OR – if not currently available - can be gathered with minimum effort (-). In some cases (for example, the categories related to the Innovation Survey data), existing data may be quite outdated. However, it remains possible to gather data on those dimensions and indicator categories included in the (CIS) innovation survey.

Table 4: General outline of an STI Scoreboard: overview of STI indicator categories by analytical dimension
Table 4a: Inputs and enablers

Level 1	Level 2	Level 3	Domestic benchmarking	International benchmarking
Inputs and enablers: Invest and expenditure	Public expenditure on R&D	GERD by Sector	√	√
		GERD by type of R&D	√	√
		GERD by socio-economic objective	√	√
		Funding of R&D by source	√	√
		GBARD	√	√
		Tax reliefs and incentives	√	√
	Innovation expenditure	In-house and external R&D (% of innovative enterprises)	√	√
		Innovation expenditure by type of expenditure (%)	√	√
	Venture capital	Total venture capital expenditure	√	√
		Venture capital (% GDP)	√	√
		Venture capital by sector (%)	√	√
Inputs and enablers: Human capability	R&D Personnel and Researchers	R&D Personnel and researchers by sector	√	√
		R&D Personnel and researchers by field	√	√
		R&D Personnel and researchers by gender	√	√
	Academic staff (HE)	Staff capacity (HC) (total and by university)	√	
		Staff capacity (FTE) (By field and qualification)	√	
		Staff diversity (gender, race, nationality, age)	√	
	Postdoctoral fellows	Postdoctoral fellows (HC by field	√	
	Doctoral students	Doctoral enrolments (by field)	√	
		Doctoral enrolments - demographics (gender, race, age, nationality)	√	
Inputs and enablers: Infrastructure and equipment	Research infrastructure and equipment	Capital expenditure on R&D	√	√
		NRF funding of research equipment	√	
	ICT infrastructure	ICT Broadband penetration	√	√
	E-readiness	E-government readiness index		√

Table 4b: Flows and linkages

Level 1	Level 2	Level 3	Domestic benchmarking	International benchmarking
Flows and linkages	Knowledge flows and mobility	Students (inbound and outbound mobility rates)	√	√
		Students (employability rates) by sector, field	-	
		Postdoctoral fellows (inbound and outbound mobility rates)	-	
		Postdoctoral fellows (employability rates) by sector, field	-	
	Scientific collaborations	Academic collaboration (co-authorship) by type, field, country	√	√
		University-industry collaboration (co-authorship/ citations to patents)	√	√
	Area-based connections	Micro-clusters of topics in science and between science and society	√	√
	Scientific networks	Co-author networks (by field/ country/ sector)	√	√
	Technology transfer	Spin-out companies	√	√
	Partnerships	University-industry partnerships (co-funding/ joint projects	-	
		(Funding) acknowledgements to industry	-	√
		Web-links to industry	-	

Table 4c: Outputs

Level 1	Level 2	Level 3	Domestic benchmarking	International benchmarking
Outputs (Students)	Bachelors graduates	Stocks: Headcounts (by field, SET, university)	√	√
		Diversity (race, gender, age) by field, university	√	
	Honours students (HE)	Stocks: Headcounts (by field, university)	√	
		Diversity (race, gender, age) by field, university	√	
	Masters students	Stocks: Headcounts (by field, SET, university)	√	√
		Diversity (race, gender, age) by field, university	√	
	PhD's	Stocks: Headcounts (by field, university)	√	√
		Diversity (race, gender, age) by field, university	√	
		PhD's per million of population	√	√
Outputs (Scientific publications)	Publications	Publications (full and fractional counts/ % world share/% Africa share)	√	√
		Publications (Relative field strength index/Activity Index)	√	√
		Publications by document type (books/ articles/ conference proceedings/ dissertations)	√	√
		Publications by field (different levels of disaggregation)	√	√
		Publications by sector (and by field)	√	√
	Authorships	Authorships by document type and field	√	√
		Authorships by demographic category and field	√	
Outputs (Technology)	Patents	**Patents (applications) count and per capita**	√	√
		Patents by office (%)	√	√
		Patents - granted (residents/non-residents)	√	√
		Patents - patent family applications by office	√	√
		Patents - per R&D expenditure	√	√
		Patents - by technology (count and % world share)	√	√
		Invention disclosures	√	√
	Trademarks	Trademark (per million PPP$ GDP)	√	√
		Trademark by Nice classification	√	√
		Trademark by office (count and world share)	√	√
	Designs	Designs (count and per GDP)	√	√

Level 1	Level 2	Level 3	Domestic benchmarking	International benchmarking
Outputs (Technology)	**Designs**	Designs by office % world share	√	√
	Plant breeder rights	Plant breeder rights granted by organisation	√	√
	Exports (goods)	High and medium-tech exports (per capita/ US$ millions)	√	√
		Export performance by merchandise (% SA share)	√	√
		Export performance by merchandise (% world share)	√	√
	Exports (services)	Knowledge intensive services exports		√
		Hi-tech knowledge intensive: Number of enterprises		√
		TCI service exports		√
	Technology balance of payments (TBP)	Technology Payments % GDP	√	√
		Technology Payments % GERD	√	√
		Technology Payments (million US$)	√	√
		Technology Payments (R million)	√	√
		Technology Payments per capita	√	√
		Technology receipts % GDP	√	√
		Technology receipts (R million)	√	√
Outputs (enterprises)	**Innovative enterprises**	Percentage of innovating firms (Innovating Firms (as % of total enterprises)	√	√
		Innovative enterprises by type of innovation	√	√
	Innovation rates	Innovation rates in firms by sector	√	√
	Innovation partnerships	Innovation partnership by type of partnership	√	√

Table 4d: Impacts

Level 1	Level 2	Level 3	Domestic benchmarking	International benchmarking
Impacts (scientific)	**Citation impact**	Field-normalised citation score (by field/ institution)	√	√
		Highest citations (top 1%pp; top 5%pp; top 10%pp)	√	√
	Readership	Mendeley readers (MRS)	√	√
	Altmetrics	Twitters; blogs, policy documents, Wikipedia citations	-	√
	Educational impact	Documents saved by students	√	√
	Socio-economic relevance and impact	Scientific papers mapped to SDG goals	√	√
	Citations in clinical guidelines	Citation in clinical guidelines	-	√
Impacts (technological)	**Technology transfer indicators**	Number of outreach activities to identify business ideas		
		Number of spin-offs	√	√
		Number of licenses	√	√
		Number of start-ups	√	√
		Value creation measure (operating profit and total salaries in spin-off firm portfolio)	√	√
Impacts (economic and developmental)	**Economic growth and wealth creation**	Employment growth	√	√
		Sales of start-ups	√	√
		Introduction of new products to market	-	√
	Inclusive development	Indicators of social innovation	-	-
		Indicators of grassroots innovation	-	-

A note on socio-economic impact: It has become conventional practice in some STI scoreboards to include indicators or indices related to socio-economic goals such as quality of life, job creation, social progress and cohesion and the like. We have seen this in the NRDS examples in Section 3 and this practice is also followed in the NACI reports. All of these indicators or indices are attempting to link some kind of societal impact to science, technology and innovation. However, it is well-documented that the link between these societal impacts – especially of science and technology – is not well codified in standardised indicators. Problems around causal attribution, time delays, the influence of extraneous variables and serendipity as well as field differences simply mean that it is extremely difficult to capture the societal impact of science and technology in a single number or ratio. Our suggestion, below, is that some of these 'constructs" (social progress, quality of life, competitiveness and level of human development) are best included as contextual variables (predominantly indices) that form the background to the scoreboard presented here.

Some of the dimensions in this version of the scoreboard need to be further unpacked to assess their relevance for M&E framework implementation. For example, counting patents as one of the 'Technology Output' indicators may prove less relevant, but monitoring and measuring the fraction of those patents that are licensed is an indicator of the commercial value of that invention. Such patents may lead to technological innovations in the marketplace that generate new economic activity and job creation. The structure presented in **Table 4** and the underlying measurement frameworks will, inevitably, contain many information gaps. Some are highly problematic because they refer to essential, yet missing, data.

Some of the STI indicator categories in **Table 4** are fairly traditional and well-developed, such as the 'Investment and expenditure' and 'Science Outputs' categories. The 'Technology Output', focussing on the technological development part within business sector R&D processes is much less developed. Capturing R&D in the private sector is more complicated because it often involves the entire chain of interconnected R&D activities (from basic research and innovative ideas, to applied research, as well as testing of prototype technologies) up to near-market innovation activities (such as branding and marketing). Other indicator categories are even more difficult to fill in with carefully selected measures - either because of conceptual ambiguities, technical or methodological difficulties, and lack of useful empirical information or statistical data. Take for example the 'Innovation Outputs' category, where some quantitative indicators and data can be extracted from the SA Innovation Survey (on SA firms). Unfortunately, there has not been a recent implementation of this survey which compromises the reliability of the data.

The broad class of STI indicators with regards to 'innovation' deserve a special mention, given the pivotal importance of the NSI as a dominant perspective on the structure and functioning of the STI system (see also Box 2 in section 4).[12] Defining 'innovation' needs to be broader than technological innovation with related economic impacts. Gathering high-quality comparative information on small services-sector firms or those in the informal sector will require a significant effort and investment in indicator development and data infrastructures. A more holistic understanding of innovation is needed that encompasses the whole STI system (and relevant parts of the higher education system) and includes societal impacts. Adopting a broader conceptualisation of 'innovation' and an impact-driven approach, the measurement framework should prioritise those indicator groups and indicators that capture innovation-based socio-economic goals as best as possible. We need to include 'social innovations', 'inclusive innovations' and other types of new, innovative outputs and impacts. Only then can we define and interpret those impacts more broadly, in terms of "direct or indirect impacts from the SA STI system that (can) create benefits for SA society and economy".

[12] *Although many South African STI policies specifically acknowledge NSI as a general framework, and target elements thereof, here we treat the NSI and the STI system as equivalents or largely overlapping systems.*

The Oslo Manual on Innovation (EC/OECD, 2018; p. 215), devoted entirely to business sector innovation, describes these indicators as:

> *"An innovation indicator is a statistical summary measure of an innovation phenomenon (activity, output, expenditure, etc.) observed in a population or a sample thereof for a specified time or place"*, while arguing that ...
> "Innovation indicators can be constructed from multiple data sources, including some that were not explicitly designed to support the statistical measurement of innovation.
>
> *Relevant sources for constructing innovation indicators include innovation and related surveys, administrative data, trade publications, the Internet, etc."* and … *"*
>
> *Although increasingly used within companies and for other purposes, indicators of business innovation, especially those from official sources, are usually designed to inform policy and societal discussions, for example to monitor progress towards a related policy target"* while noting that high-quality indicators should have …
>
> *"… desirable properties of innovation indicators include relevance, accuracy, reliability, timeliness, coherence and accessibility"*

Gathering information on these business sector components can be challenging. In the current stage of development, we are also facing missing information on: non-economic innovation impacts (such as inclusive innovations); SA-specific transformation goals (for example, specific programmes to boost employment of university graduates in SA industries); Policy coordination and alignment (e.g. among SA government departments or agencies to promote knowledge-based innovation); Human capability (such as the number of university students engaged in innovation-promoting courses).

Note that the overview in **Table 4** may also include multi-measure 'composite indicators' (such as GERD/GDP) or an even more sophisticated 'index', an 'overall indicator'. The latter type is mentioned explicitly on page 28 of White Paper: *"A composite South African Innovation Index will be developed that responds to the specific needs of the country, for example, in terms of skills development, inclusive economic growth and transformation. Furthermore, to ensure that research remains responsive, a system for evaluating research and reflecting on its impact will be developed and institutionalised."*

Current surveys of the South Africa's NSI, or its STI system, will not cover the full spectrum of STI activities that are important for South Africa's social and economic well-being. Manzini, for example, proposes additional indicators with regards to: 'knowledge demand'; 'knowledge mobilisation'; 'knowledge application'; 'knowledge flow'; 'social impact'.[13] Further selection or prioritisation of individual indicators, mostly to identify strong indicators, involves further considerations and criteria that are specific for lower levels within the STI system (policies, programmes), which are outside the scope of this M&E framework proposal.

Moving towards a STI Scoreboard, which Level 1 or 2 indicator categories and Level 3 or 4 individual indicators could be fed into it? To address this question we have to ask ourselves: what is the main M&E objective of the scoreboard? Is it a detailed historical benchmarking within South Africa, is it international comparative benchmarking, or perhaps both? And secondly, how comprehensive should the scoreboard be in terms of its Level 1 and 2 dimensions? When selecting and applying indicators, one faces a trade-off between feasibility and comprehensiveness, and between quantity and quality. Indicator selection needs to be driven by considerations of policy relevance, information value, and technical credibility. The selected indicators should present a workable and cost-effective 'fit for purpose' solution that is acceptable and useful for all major users and key stakeholders.

The South African STI Scoreboard should try to include such indicators as much as possible. Given the current development stage of the SA STI system, there is a clear

[13] *Manzini S. (2015). Measurement of innovation in South Africa: an analysis of survey metrics and recommendations. South African Journal of Science;111(11/12), http://dx.doi.org/10.17159/*

need for 'Flow and Linkages' indicators to test whether the building blocks of interactions, partnerships, relationships, and other beneficial connections and collaborations are increasing or becoming more effective. There are also several policy intents in the White Paper that touch on topics where such indicators are needed, such as the White Paper's Policy intent 4.1 ("Support innovation for social and grassroots innovation"). Collecting information and designing appropriate indicators will take time, but it is feasible in several cases. The White Paper also includes several policy intents that touch on issues of Policy coordination and alignment, which could also serve as input to information gathering and a qualitative (case study based) indicator. Universities should also be able to provide statistics on the (estimated) numbers of students (masters or PhD) that have enrolled in in-house entrepreneurship courses or are involved in innovation activities.

Similarly, to the European Innovation Scoreboard (see **Figure 16)**, a series of 'contextual indicators' are required to 'normalise' performance indicators or interpret the general findings. Probably the most well-known (as well as controversial) of such indicators is the share of the national GDP spend on R&D, a macro-level economic statistic of a country's general wealth level. The indicator 'GDP per capita' provides a (very crude) micro-level estimate for each inhabitant. Such contextual indicators may provide background information on relevant demographic developments and economic developments, but also business sector structure, as well as governance and policy frameworks. Any indicator-based system-level M&E framework, should include contextual indicators to provide appropriate background information for fair assessments of STI performance.

Figure 16: Contextual indicators as background information

	Time period	Information source
PERFORMANCE AND STRUCTURE OF THE ECONOMY		
GDP per capita (PPS)	Average 2015-2017	Eurostat
Average annual GDP growth (%)	2016-2018	Eurostat
Employment share Manufacturing (NACE C) (%)	Average 2015-2017	Eurostat
… of which High and Medium high-tech (%)	Average 2015-2017	Eurostat
Employment share Services (NACE G-N) (%)	Average 2015-2017	Eurostat
… of which Knowledge-intensive services (%)	Average 2015-2017	Eurostat
Turnover share SMEs (%)	Average 2013-2016	Eurostat
Turnover share large enterprises (%)	Average 2013-2016	Eurostat
Foreign-controlled enterprises – share of value added (%)	Average 2014-2016	Eurostat
BUSINESS AND ENTREPRENEURSHIP		
Enterprise births (10+ employees) (%)	Average 2014-2016	Eurostat
Total Entrepreneurial Activity (TEA) (%)	Average 2016-2018	Global Entrepreneurship Monitor
FDI net inflows (% GDP)	Average 2015-2017	World Bank: World Development Indicators
Top R&D spending enterprises per 10 million population	Average 2016-2018	EU Industrial R&D Investment Scoreboard
Buyer sophistication (1 to 7 best)	Average 2016-2018	World Economic Forum

GOVERNANCE AND POLICY FRAMEWORK		
Ease of starting a business (0 to 100 best)	Average 2016-2018	World Bank: Doing Business
Basic-school entrepreneurial education and training (1 to 5 best)	Average 2016-2018	Global Entrepreneurship Monitor
Government procurement of advanced tech products (1 to 7 best)	Average 2015-2017	World Economic Forum
Rule of law (-2.5 to 2.5 best)	Average 2015-2017	World Bank: Worldwide Governance Indicators
DEMOGRAPHY		
Population size (millions)	Average 2015-2017	Eurostat
Average annual population growth (%)	2016-2018	Eurostat
Population density (inhabitants/km^2)	Average 2015-2017	Eurostat
INDICES		
Environmental Performance Index Gender Development Index Score on social progress performance Human Development Index Rank		

The Logic model that underpins the proto-framework of the STI Scoreboard does not necessarily have to be the only source of guidance on selecting analytical dimensions and indicator categories. The NACI-commissioned synthesis report, to review an earlier version of the White Paper on Science and Technology (Walwyn, 2016)[16], introduces a complementary perspective. It mentions the following six cross-cutting 'High-Level Framings', each of which aim to "transform system capability into competence": Accelerating Business Innovation; Strengthening Synergies and Partnerships; Innovating for Social Benefit; Providing the Skills for Innovation, Education and Training; Improving Delivery and Service, Innovation in the Public Sector; Monitoring, Evaluation and Learning. Each of those six 'system dimensions' presents a list of recommended indicators, many of which would fit into one or more of categories included in **Table 4**. For example, the 'Monitoring, Evaluation and Learning' Frame consists of four performance indicators, such as 'Proportion of programmes, including incentives and instruments, which are formally evaluated'.

Only when sufficient information is made available – across the key components of the SA STI system and various policy objectives – and high-quality, credible 'key performance indicators' have been developed and tested, can one engage in the computation of a 'South African Innovation Index', a single statistic capturing the overall performance of the SA innovation system fed by those KPIs. Which indicators should form part of that Index, and how their relative contributions should be determined and weighted, is a matter of further data-analytical research and consultation with stakeholders.

In conclusion: The proposed SA STI Scoreboard should form the core 'high-profile' element in the M-part of the M&E framework. The Scoreboard could act as a structuring device, and incentive tool, to shape and drive STI data collection across the entire STI system. It should be fed and supported by several other analytical tools or information sources on monitoring components of the STI system, such as research programmes, knowledge-producing universities, public-private R&D networks, science and innovation hubs, and innovation-driven business enterprises. There are still remaining gaps between the currently applied set of quantitative indicators and those that are probably needed to conduct a full-scale assessment of the STI system.

[14] *Walwyn, D. (2016). Synthesis report; Review of the White Paper on Science and Technology and High Level Framing for a New Decadal Plan, NACI report, February 2016.*

CREST is in the process of developing a large-scale 'STI Indicator Bank', specifically aimed at providing a tentative classification system of STI indicators and assembling indicators to be considered for M&E usage in an STI Scoreboard and/or an STI Index. Most categories in the CREST STI Indicator Bank are now populated with one or more quantitative indicators. More of those indicators will be added in the coming months. Currently, the share of the STI indicators with recent data on the performance of SA actors remains limited. To expand and upgrade this list, focussing on technical feasibility and data availability of key performance indicators, and gathering the necessary high-quality data will require a substantial investment in information infrastructures and human capability.

Section 6

Evaluation

6.1 The 2019 White Paper on STI as an analytical framework

Effective evaluations should be guided by the questions we want to answer and appropriate M&E models, not by predefined analytical toolkits, misguided performance indicators, or outdated epistemological traditions. As indicated in the introduction to this report, we follow a theory-based evaluation (TBE) approach to M&E. TBE requires that both the evaluation and monitoring components of a M&E framework are embedded within an explicit theory or theories of change. Given the complexity of STI systems, it is often difficult to formulate a single high-level theory of change that applies to an entire policy domain. In such cases domain-specific ToCs might be required. As indicated in subsection 3.1 of the report, there are five key steps in TBE processes:

1. Formulate a plausible programme theory;
2. Formulate and prioritise evaluation questions;
3. Use programme theory to guide the evaluation;
4. Collect and analyse data focussing on programme theory and evaluation questions;
5. Test the theory.

In this section, we report on two different approaches to constructing a TBE-approach to STI evaluations. The first approach is based on a national policy document (the current White Paper); the second, on an analytical framework of the STI system (the adapted Kuhlmann and Arnold framework as depicted in **Figure 12**). We have already shown that it is common practice in STI-evaluations to frame monitoring and evaluation questions based on some national policy, strategy or plan. In our discussions of the NRDS and TYIP (both of which emerged out of the 1996 White Paper), we (re)constructed their theories of change and showed how monitoring questions (and indicators) can be derived from such theories of change (even if incomplete and not entirely cohesive). In this section, we follow the same procedure and extracted from the new White Paper (2019) a set of possible evaluation questions that can guide M&E in the system in the near future (section 6.2). We subsequently mapped these evaluation questions (clusters) to the Kuhlmann and Arnold framework as a first validation test for their coverage and relevance. It is important to emphasise that these questions are simply illustrative as the further articulation and operationalisation of the White Paper into the decadal plan will undoubtedly generate more evaluation questions.

Our second approach took the Kuhlmann and Arnold analytical framework as our point of departure. Focussing on the main systems and sub-systems components, as well as the ideal linkages between these, we generated a second (higher-order) list of evaluation questions (section 6.3). Again, this list should be taken as illustrative and provisional.

In summary: we describe the two approaches to generating STI-related evaluation questions below: the first deriving more domain-specific evaluation questions from the current White Paper; the second, inferring system-wide evaluation questions from an analytical framework of the STI-system. It is easy to see that these two approaches are and should be read as complementary to each other. It is also obvious that other methodologies can be employed to either elaborate and/or refine on these two preliminary lists, e.g. through stakeholder engagements, Delphi-surveys and scenario-building.

6.2 Domain-specific evaluation questions

Applying this TBE process, we turn our attention to the current White paper on Science, Technology and Innovation which was approved in March 2019.[15] The White Paper introduces, on page 11, its vision statement:

"The White Paper proposes policy actions to achieve its vision according to the following conceptual logic:

[15] *The next step in the STI policy implementation process – the development of a decadal plan – entails the further operationalisation and elaboration of the policy into measureable interventions (with clear activities, outputs, outcomes, impacts and quantitative and qualitative indicators). The development of the new decadal plan for STI is currently under way and is expected to be produced by mid-2020. This means that we could not use the White Paper in any strong sense as a heuristic framework as input to our proposed M&E Framework.*

- *The premise of this White Paper is that STI, being significant contributors to inclusive and sustainable development, can shape a different South Africa.*
- *It is through partnerships between business, government, academia and civil society that the potential contribution of STI to addressing South Africa's socio-economic development challenges will be realised.*
- *The success of these partnerships will require a coherent whole-of-society STI agenda, the collaboration of all NSI partners in pursuing this agenda, and for all NSI partners to regularly reflect on and learn from the implementation of STI initiatives.*
- *Specific STI-related challenges, such as insufficient skills and funding, as well as constraints in the business environment for innovation, will also need to be addressed for the partnerships to have an optimal impact.*
- *To make all of the above possible, society will need to value science, appreciate the impact of innovation on development, and anticipate and plan for change. A society that is permeated by a culture of creativity, learning and entrepreneurship will provide a fertile environment for harnessing the potential of STI."*

Box 3. Overview of explicit 'Policy intents' in the White Paper

CHAPTER 3: A COHERENT AND INCLUSIVE NATIONAL SYSTEM OF INNOVATION

1.1. Enhance policy coherence and programme coordination in the NSI
1.2. Strengthen the governance of public NSI institutions
1.3. Expand the NSI
1.4. Upgrade the M&E and policy capacity of the NSI

CHAPTER 4: AN ENABLING INNOVATION ENVIRONMENT IN SOUTH AFRICA

1.1. Brand South Africa as an innovative country
1.2. Adopt a broader conceptualisation of innovation beyond R&D
1.3. Adopt a whole-of- society approach to innovation
1.4. Use public procurement as a vehicle to further innovation
1.5. Increase support for, and collaboration with the business sector
1.6. Policy intent: Support commercialisation of publicly funded intellectual property
1.7. Ensuring that legislation on intellectual property rights from publicly financed research and development responds to the changing policy context
1.8. Increase the spatial footprint of innovation in South Africa
1.9. Support innovation for social and grassroots innovation
1.10. Exploit new sources of growth
1.11. Innovation to revitalise existing sectors
1.12. Strengthen government's role as an enabler for innovation

CHAPTER 5: INCREASED HUMAN CAPABILITIES AND AN EXPANDED KNOWLEDGE ENTERPRISE

5.1. Expanding research outputs and transforming the research institutional landscape
5.2. Transform the profile of the researcher base
5.3. Improve the research system's output of human capabilities
5.4. Strengthen skills in the economy
5.5. Ensure an open, responsive and diverse knowledge system
5.6. Support a science-literate and science-aware society
5.7. Upgrade and expand research infrastructure
5.8. Expand internationalisation and science diplomacy

CHAPTER 6: FINANCING SCIENCE, TECHNOLOGY AND INNOVATION

6.1. Increase levels of funding
6.2. Develop funding priorities
6.3. Institutionalise a framework for guiding public STI investment
6.4. Improve funding efficiencies

It is not uncommon that policy documents do not have a clear and explicit ToC. We have, therefore, embarked on an experiment to see how far we can proceed with the above-mentioned five-step TBE process. This ‘experiment’ consists of three phases: first, we extracted from the White Paper a possible theory of change; second, we commenced with identifying possible evaluation questions (EQ’s) contained - sometimes explicitly and sometimes implicitly - in the White Paper (see **Appendix 4**); and third, we subsequently clustered these EQ’s under more general headings and STI domains.

The White Paper provides some useful ordering of the interventions around explicitly mentioned ‘policy intents’ (see **Box 3)**. Each of those intents refers to specific aspirations and initiatives to tackle STI system constraints. We focus our attention on M&E applicable policy intents that are accompanied by an ‘actionable item’ - in terms of an explicitly proposed measure, initiative or intention - that can be translated into an ‘evaluation question’. Such a question can be addressed – in principle – in terms of suitable empirical information and appropriate indicators.

Timelines are not explicitly mentioned in any of the EQs, which is obviously an essential methodological parameter in the context of a Logic model. However, the White Paper mentions, on page 25, a three-year evaluation cycle in its policy intent 3.3.1 (‘Coherence of the NSI at the system level: A Ministerial Structure on STI’):

> *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 Department of Planning, Monitoring and Evaluation (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 reviewing reports on the performance of the NSI over three-year cycles.*

We will therefore assume that EQs involve a policy trajectory time-line, from ‘Objective’ to a desired ‘Input’, which would take at least two or three years. Some ‘Outputs’ may also occur within this time-period, but we consider this less likely. Longer-term ‘Results’ or ‘Impacts’ are highly unlikely but are included if such expected achievements are explicitly mentioned, or implicitly implied, in an EQ.

Table 5 provides an overview of all potential EQs extracted from the White Paper organised by ‘policy intent’ and ‘STI-domain’. A subset of ‘M&E-applicable’ policy intents and EQs in the White Paper is derived from a selection process following three analytical steps:

(1) developing **‘domain-specific evaluation questions’** (D-EQs), for as many of those policy intents as possible, based on a series of selection criteria (see below in **Box 4**);

(2) D-EQs are subsequently collated and mapped into *‘EQ clusters’* according to policy-relatedness and/or their position within a Logic model;

(3) ‘information scoping’ of those EQ clusters against required analytical infrastructures, (potentially) available information sources, and feasible data-collection methodologies.

Box 4. Key criteria for selecting D-EQs

Viable and relevant EQs should, ideally, comply with the following selection criteria:

1. Policy issues and goals are sufficiently aligned with (a) the object of analysis (i.e. performance of the STI system); (b) theoretical or conceptual models; (c) analytical model of Logic model
2. Those issues and goals are addressable in terms of: (a) observable and recognisable entities; (b) identifiable inputs, processes, (intermediate) outputs, outcomes or impacts
3. Relevant features of these elements can be captured appropriate information collection tools (either opinion-based, fact-based, or a mix of both; either SA or international sources; either small-scale case studies or large-scale comprehensive statistics).
4. The required information lends itself for (a) internal or external verification; (b) high-quality indicators - either qualitative ('narratives') or quantitative ('metrics').

Moving towards operationalisation, the availability of required empirical information in South Africa, or the possibility to gather reliable and verifiable information, to address D-EQs is a major practical concern. One needs to develop data collection strategies and infrastructures, and data management tools. As for data collection, one should distinguish between the following general categories to represent the likelihood of facing obstacles in terms of being able to systematically collect high-quality (accurate, complete) information:

- Available - readily available and accessible;
- Feasible - not readily available/accessible, but collection is likely to be feasible;
- Problematic - not readily available/accessible; may prove difficult or impossible to collect;
- Non-existent – the information currently does not exist and hence needs to be developed and made accessible;
- Unknown – information status is unclear; may require verification or validation.

Table 5: Overview of the White Paper's policy intents and evaluation questions: policy areas; STI domains; actionable initiatives

Policy area	STI Domain	Policy intent	Actionable initiative (to be evaluated)
1	Innovation for inclusive development	Policy intent 4.9: Increase the spatial footprint of innovation in South Africa	*"Local and provincial growth and development strategies will include innovation plans."*
1	Innovation for inclusive development	Policy intent 4.9: Increase the spatial footprint of innovation in South Africa	*""Innovation hubs" will be expanded to enhance provincial growth and development strategies, and promote provincial technology competencies."*
1	Innovation for inclusive development	Policy intent 4.9: Increase the spatial footprint of innovation in South Africa	*..."cooperative research centres (involving industry, science councils and HEIs) and local innovation ecosystems will be developed"...*
1	Innovation for inclusive development	Policy intent 4.9: Increase the spatial footprint of innovation in South Africa	*..."a "no wrong door" policy will be adopted across government, particularly at local and provincial government level, which will see innovation-related enquiries routed efficiently to provide the required information or support."*
1	Innovation for inclusive development	Policy intent 4.3: Adopt a broader conceptualisation of innovation beyond R&D	*"The DST will continue to champion innovation for inclusive development, especially in the context of developing and empowering both urban and rural communities."*
1	Innovation for inclusive development	Policy intent 4.1: Support innovation for social and grassroots innovation	*"Support for grassroots innovation will be a planning priority in all relevant initiatives. It will be funded accordingly, and monitored in all relevant M&E frameworks."*
1	Innovation for inclusive development	Policy intent 4.1: Support innovation for social and grassroots innovation	*"Developers of local economic development plans, as well as provincial growth and development strategies, will be encouraged to include support for grassroots innovation, and innovation scouting in plans."*
1	Innovation for inclusive development	Policy intent 4.1: Support innovation for social and grassroots innovation	*"Government will further leverage the potential of publicly funded IP to support grassroots innovation. South Africa will develop a country-specific, second-tier patent system, offering a cheap, no-examination protection regime for technical inventions that would not usually fulfil the strict patentability criteria."*
1	Innovation for inclusive development	Policy intent 4.1: Support innovation for social and grassroots innovation	*..."government will work with NSI partners to develop an appropriate funding instrument for grassroots innovation."*
1	Innovation for inclusive development	Policy intent 4.11.2: Greening the economy	*..."The DST will therefore work with the relevant NSI partners to develop an STI approach to greening the economy, as well as to fund the required research and capabilities."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
2	Framework conditions: incentives	Policy intent 4.13: Strengthen government's role as an enabler for innovation	*"To help entrench a culture of innovation in government, the DST will work with the Centre for Public Service Innovation (CPSI) and other relevant national, provincial and local agencies on challenging the risk-averse mind-set of public servants, using awards to motivate them and celebrating role models. More specifically, the DST will work with the CPSI to increase service delivery through initiatives such as e-government."*
2	Framework conditions: incentives	Policy intent 6.5: Improve funding efficiencies	*"In line with recommendations of the Review of Government Business Incentives led by the DPME, a possibility to consolidate the number of incentives currently available, under a few well-functioning lead agencies, will be investigated."*
2	Framework conditions: procurement	Policy intent 4.5: Use public procurement as a vehicle to further innovation	*"A supportive legislative environment will be ensured"…*
2	Framework conditions: procurement	Policy intent 4.5: Use public procurement as a vehicle to further innovation	*…"strategies will be developed to ensure that government is the first customer when it comes to using locally developed technologies."*
2	Framework conditions: procurement	Policy intent 4.5: Use public procurement as a vehicle to further innovation	*"Technology conditionality will be built into large procurement contracts"…*
2	Framework conditions: procurement	Policy intent 4.5: Use public procurement as a vehicle to further innovation	*"The Competitive Supplier Development Programme, championed by SOEs, will also be expanded to include local technologies."*
2	Framework conditions: procurement	Policy intent 4.5: Use public procurement as a vehicle to further innovation	*"The role of the Public Finance Management Act, 1999 in R&D-related activities will be made clear"…*
2	Framework conditions: Funding	Policy intent 6.5: Improve funding efficiencies	*"To simplify the application processes and reduce duplication, the functions and funding instruments of the following institutions, among others, will be harmonised: the TIA, NIPMO, relevant sections of the Small Enterprise Development Agency, the Technology and Human Resources for Industry Programme, the Support Programme for Industrial Innovation, elements of the IDC, and parts of the NRF. The intention is to ensure a seamless transition between functions and instruments."*
2	Framework conditions: Mobility	Policy intent 5.9: Expand internationalisation and science diplomacy	*"The intent is to secure at least 15 per cent of South Africa's GERD from international sources, and to grow this ratio over time."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*"New funding models across the innovation value chain will be used. Examples include corporate social investment, crowd funding, and partnerships/collaborations between actors across different sectors and borders. The growing sector of corporate social investment funds and non-profit organisations presents opportunities to advance grassroots and social innovation, for example, through venture capital funding. Government will introduce instruments such as matching funding and awareness raising to make greater use of these opportunities.""*
2	Framework conditions: Funding	Policy intent 6.5: Improve funding efficiencies	*"Government's information on public support for business R&D and innovation will be improved appropriately, taking cognisance of the need for sharing restrictions."*
2	Framework conditions: Funding	Policy intent 4.6.2: Targeted technology development and deployment to support firms	*"Sectors with growth potential will be targeted for funding support, e.g. through expanded sector innovation funds."*
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*"A Sovereign Innovation Fund will be formed to leverage co-investment by the public and private sectors to address gaps in technology commercialisation."*
2	Framework conditions: Funding	Policy intent 3.5.2: Expansion of the scientific knowledge base of the NSI	*…"implementing overarching measures to expand the science base of the NSI, including increased public investment in scientific research."*
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*"Government recommits to the target of increasing the intensity of R&D investment in the economy so that GERD reaches 1.5 per cent of GDP in the next decade, and an aspirational 2 per cent a decade later."*
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*…"systems will be put in place to ensure funding efficiencies."*
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*"National STI-intensive government departments will set appropriate targets for STI in their budgets. In particular, line departments will commit a percentage of their budgets for sectoral RDI plans, and will invest in the science councils that report to them accordingly."*
2	Framework conditions: Funding	Policy intent 6.2: Increase levels of funding	*"Provincial and local governments will actively contribute more to STI funding and, over time, will set appropriate targets for investment in STI as part of their growth and development strategies."*
2	Framework conditions: Funding	Policy intent 5.2: Expanding research outputs and transforming the research institutional landscape	*"The university funding formula that was introduced in 2003 had a positive effect on research outputs. Incentives of this nature will be investigated to also support research that informs society, for instance research that improves quality of life."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
3	Governance and co-ordination	Policy intent 3.2: Improve inclusion and build more linkages across the NSI	*…"effort will be directed at strengthening collaborative R&D instruments such as Centres of Competence, and Sector Innovation Funds."*
3	Governance and co-ordination	Policy intent 3.3.6: Horizontal and sector/thematic coordination	*"Sector Innovation Funds, which have been introduced mainly in the agriculture and mining sectors, will be enhanced and expanded to include other priority sectors."*
3	Governance and co-ordination	Policy intent 3.3.6: Horizontal and sector/thematic coordination	*"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."*
3	Governance and co-ordination	Policy intent 3.4: Strengthen the governance of public NSI institutions	*…"a policy framework will be developed to describe the purpose, functions and governance of Public Research Institutions relevant to national development as guided by the NDP, taking into account the roles of all stakeholders."*
3	Governance and co-ordination	Policy intent 3.5.2: Expansion of the scientific knowledge base of the NSI	*…"DST will work with line departments and business to develop sector STI plans"...*
3	Governance and co-ordination	Policy intent 3.5.2: Expansion of the scientific knowledge base of the NSI	*"The DST will further coordinate support for foundational aspects of the NSI"…*
3	Governance and co-ordination	Policy intent 4.4: Adopt a whole-of-society approach to innovation	*"The current contributions of the NSI to IPAP will therefore be deepened to ensure that the programmes of science councils are aligned with priority industrial sectors, as well as with new growth opportunities identified by, among others, the Industrial Development Corporation (IDC)."*
3	Governance and co-ordination	Policy intent 4.4: Adopt a whole-of-society approach to innovation	*"STI will be integrated into future frameworks and legislation to advance national industrial and economic objectives."*
3	Governance and co-ordination	Policy intent 4.4: Adopt a whole-of-society approach to innovation	*"An important step towards aligning STI and industrial policy will be the establishment of the proposed policy nexus on trade and investment."*
3	M&E	Policy intent 3.4: Strengthen the governance of public NSI institutions	*"An appropriate evaluation framework will be put in place to enable objective assessment of their efficiency levels."*
3	M&E	Policy intent 3.4: Strengthen the governance of public NSI institutions	*"The ambitions underpinning this White Paper – excellence, inclusion, partnerships and pan-African collaboration – will be built into the evaluation framework."*
3	M&E	Policy intent 5.6.2: Diversity of knowledge fields	*"Studies on the state of health of the different knowledge fields in South Africa will be intensified to allow the DST and other funding institutions to deploy research funding strategically and sustainably."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
3	M&E	Policy intent 5.7.3: The reach and effectiveness of science engagement activities	*"Indicators to measure the success of system-wide science engagement performance will be adopted to inform an institutionalised survey on public perceptions of science and country comparison studies."*
3	M&E	Policy intent 6.4: Institutionalise a framework for guiding public STI investment	*"The DST, working with NACI, will develop a public STI investment framework. NACI's role will be to undertake foresight studies and provide an independent STI M&E function (including regular analysis of public STI spending)."*
3	M&E	Policy intent 5.9.3: Planning and coordination for international cooperation	*"Indicators and an M&E framework will be developed to better gauge the impact and outcomes of international STI partnerships. This will include systems for enhanced knowledge management of all South Africa's international STI cooperation initiatives (government and business)."*
4	Knowledge infrastructure: IP	Policy intent 4.3: Adopt a broader conceptualisation of innovation beyond R&D	*"Appropriate access mechanisms to the formal intellectual property rights (IPR) registration system will be introduced to ensure that all innovations, regardless of source and nature, may find protection, where relevant and desirable."*
4	Knowledge infrastructure: IP	Policy intent 4.3: Adopt a broader conceptualisation of innovation beyond R&D	*"The DST will continue with initiatives to strengthen the recording, protection and utilisation of this knowledge, to the benefit of the knowledge holders and the country."*
4	Knowledge infrastructure: IP	Policy intent 5.6.6: Knowledge diffusion	*…"the role of Offices of Technology Transfer needs to be enhanced, creating demand for in-bound technology transfers."*
4	Knowledge infrastructure: IP	Policy intent 4.6.4: Specific support for SMEs	*..."DST will develop guidelines, in cooperation with relevant NSI partners, to use intellectual property from publicly funded R&D under appropriate conditions to support women and black entrepreneurs when such intellectual property is commercialised."*
4	Knowledge infrastructure: IP	Policy intent 4.7: Support commercialisation of publicly funded intellectual property	*"Support for Offices of Technology Transfer will be increased through existing instruments, initially to develop capacity, and, over time, on the basis of the quantity and quality of outputs. To support the transformation of higher education, the type of government support to these offices will be differentiated according to the research intensity and technology transfer maturity of the institution in question."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
4	Knowledge infrastructure: IP	Policy intent 4.1: Support innovation for social and grassroots innovation	*"With the introduction of a substantive patent search and examination system at the Companies and Intellectual Property Commission (CIPC), a preferential accelerated patent examination system will be introduced for SMEs, broad-based black economic empowerment firms, previously disadvantaged individuals, and young innovators, depending on criteria such as the involvement of start-up firms."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"Government will therefore review these, taking into account certain aspects of IPR from publicly funded research and accepting that open science, open innovation and IP, and the associated rights, are not mutually exclusive."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"Government will also review the policies and institutions governing access to research data and research publications."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"The DST, in consultation with DTPS and DHET, will produce a national open science (and data) framework consisting of principles and guidelines for the adoption of open science in South Africa. The framework will be used as a vehicle for awareness raising and training on good practice."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"South Africa does not have formal protection for databases. Government will identify a license system for depositing data and for the use of open data."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"The current IPR Act will be reconsidered to ensure that it supports the FAIR guiding principles for scientific data management and storage. National data storage is a further matter that needs to be addressed. The DST will develop a long-term sustainable business model for a South African research data cloud."*
4	Knowledge infrastructure: Open Science	Policy intent 5.6.1: Open Science and Open Innovation	*"Therefore, government will prioritise funding for the provision of digital resources to the communities and institutions that need them the most."*
5	SME support	Policy intent 4.6.4: Specific support for SMEs	*…"initiatives aimed at developing and/or upgrading them as suppliers to government and larger firms will be scaled up."*
5	SME support	Policy intent 4.6.4: Specific support for SMEs	*"New support instruments (e.g. an R&D voucher scheme for eligible firms to cash in with registered R&D service providers) will be introduced."*
5	SME support	Policy intent 4.6.4: Specific support for SMEs	*…"consideration will be given to regulatory hurdles, as well as burdensome administration and legal requirements."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
5	SME support	Policy intent 4.6.4: Specific support for SMEs	*…"the current model for providing broad-based support to SMEs (e.g. through walk-in support at technology stations) will be scaled up to ensure that even more SMEs can access services, equipment and support in product/technology commercialisation."*
5	SOE support	Policy intent 4.6.5: Revitalising the role of SOEs in innovation	*"To turn this trend around, the following strategies will be adopted: Domestic technological knowledge gaps require the sourcing of knowledge and R&D services from abroad. For such international sourcing arrangements to be beneficial, they should be linked to a particular strategy for technology transfer and/or localisation in cases where domestic capability is inadequate. Along with the "smart buyer" principles, strategic sourcing from abroad should be linked to national imperatives for technology accumulation, so that, in the medium to long term, SOEs in specific technology spaces will buy from local service providers and institutions rather than from foreign firms."*
6	Research infrastructure	Policy intent 5.8: Upgrade and expand research infrastructure	*"Government will therefore introduce a mandatory requirement that infrastructure provision policies include human resource development support (scientific and technical) for infrastructure development and maintenance through internships, curriculum changes in HEIs, and absorption into the workplace."*
6	Research infrastructure	Policy intent 5.8: Upgrade and expand research infrastructure	*"To address this challenge, government will develop programmes and interventions that build a continuum of research infrastructure capabilities at institutional, regional and national level (vertical integration)."*
6	Research infrastructure	Policy intent 5.8: Upgrade and expand research infrastructure	*"Open-access research infrastructure support platforms will be established to encourage private sector investment in research infrastructure."*
6	Research infrastructure	Policy intent 5.8: Upgrade and expand research infrastructure	*"Government will establish an intergovernmental coordination and steering platform with a clear mandate and scope, strategy and policy guidelines, co-funding, shared procurement agreements, and joint planning principles to address the lack of coordination. Government will retain the six national research facilities currently managed by the NRF as research infrastructure platforms. The management model will therefore be changed to facilitate scale-up, sustainability and improvements in the performance and establishment of these facilities."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
7	HRD: Basic education	Policy intent 4.13: Strengthen government's role as an enabler for innovation	*"The DST will therefore work with relevant government departments, such as the DHET, the Department of Basic Education and the Department of Social Development, to develop programmes to build an innovation mind-set from early childhood."*
7	HRD: Basic education	Policy intent 5.4.2: The human resource development pipeline	*"Government will put in place specific interventions to enable all children (and, where appropriate, adults) to become digitally literate. Examples could include making greater use of mobile phone technology and existing public infrastructure in rural areas such as post offices, schools or libraries to introduce children to gaming and coding, and to teach adults digital skills. The private sector will be encouraged to partner with the government in these endeavours."*
8	HRD: Skills development	Policy intent 5.5.1: Diversity of post-secondary education	*"The sector must develop enrolment targets in line with the skills needed for the labour market."*
8	HRD: Skills development	Policy intent 5.7.2: Incentives for researchers	*"Government will aim to have these skills taken up in the curricula of SET students in the higher education sector."*
8	HRD: Skills development	Policy intent 5.4.2: The human resource development pipeline	*"Government will therefore expand its student support programmes to include the development of technical, engineering, entrepreneurship and innovation-related skills, such as in IP management."*
9	HRD: General	Policy intent 5.4.2: The human resource development pipeline	*"A framework will be developed for cooperation across government, particularly with departments that have SET postgraduate bursary programmes."*
9	HRD: Engineering	Policy intent 5.6.2: Diversity of knowledge fields	*"Given the present shortage of skilled engineers in the country, government will need to increase support for engineering science and research."*
9	HRD: PhD staff	Policy intent 5.4.1: Supervisory capacity	*"In order to increase the proportion of university staff with PhDs, direct support for attaining a PhD will be prioritised, particularly for staff at universities where the proportion of PhD-qualified staff is below the norm. Twinning programmes with research-intensive universities and international institutions will assist in addressing the shortfall."*
9	HRD: Postdoctoral fellows	Policy intent 5.4.1: Supervisory capacity	*"The DST and DHET will formalise a set of guidelines on how to optimise the contribution of postdoctoral fellows."*
9	HRD: Postdoctoral fellows	Policy intent 5.4.1: Supervisory capacity	*"Foreign postdoctoral fellows will be targeted in strategic priority areas to alleviate supervisory bottlenecks. At the same time, the DST and DHET will establish a programme for South Africans to pursue postdoctoral fellowships abroad, targeting black people and women."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
9	HRD: Transformation	Policy intent 5.4.1: Supervisory capacity	*"To improve demographic representation among established researchers, the DST and DHET will target and retain a significant number of black and women doctoral graduates, particularly South Africans, in the Postdoctoral Fellowship Programme."*
9	HRD: Transformation	Policy intent 5.3: Transform the profile of the researcher base	*"The DST and DHET will emphasise the development of black and women researchers at emerging researcher level (with a specific focus on black women), and mentor them beyond qualification to take up senior management positions in research management and science institutions. Over the short term, an increase in the number of researchers will be achieved through focused, fast-tracking interventions that will tap into the PhD-qualified, research-inactive "silent majority" of existing permanent academic staff, especially black and women staff. The DST will continue its support for the DHET's Staffing South Africa's Universities Framework, which aims to change the number and composition of university staff."*
10	R&D: Interdisciplinary	Policy intent 5.6.4: Complex societal problems and inter- and transdisciplinary	*"Funding agencies such as the NRF will support transdisciplinary research and create stepping stones for transdisciplinary careers."*
10	R&D: Interdisciplinary	Policy intent 5.6.4: Complex societal problems and inter- and transdisciplinary	*"The DST and DHET will encourage universities and science councils to intentionally promote transdisciplinary research by reducing institutional barriers to transdisciplinary research and interdisciplinary research teams."*
11	R&D: Collaboration	Policy intent 5.6.4: Complex societal problems and inter- and transdisciplinary	*"They will also develop structures to encourage input and participation from outside ongoing projects in such a way as to bring researchers from several institutions, representing multiple approaches, together in a transdisciplinary research environment."*
11	R&D: Collaboration	Policy intent 5.6.6: Knowledge diffusion	*"The contribution of Public Research Institutions and their outputs in supporting government policy and national priorities needs to be enhanced. Research grant schemes to incentivise collaboration between universities and other Public Research Institutions in inter- and transdisciplinary research will be developed."*
11	R&D: Collaboration	Policy intent 5.6.6: Knowledge diffusion	*"Government will support increased networking and the diffusion of knowledge by leveraging existing global partnerships and knowledge networks better, introducing specific programmes for the secondment of South African researchers to institutions in other countries, providing increased support for training abroad, and providing enhanced support for conferences and workshops."*

Area	STI Domain	Policy intent	Actionable initiative/to be evaluated
12	Business R&D	Policy intent 4.6.1: Supporting business R&D needs	*"Furthermore, the mining R&D hub and other instruments to support the private sector will be strengthened."*
12	Business R&D	Policy intent 4.6.1: Supporting business R&D needs	*"The incentive regime will be monitored to ensure the appropriate balance between direct and indirect support to business, with the understanding that both are needed."*
12	Technology development	Policy intent 4.6.2: Targeted technology development and deployment to support firms	*"Efforts to localise and diffuse technologies will be intensified through existing and new technology-based support interventions (including the Technology Stations Programme and the Technology Localisation Programme)."*
13	Science engagement	Policy intent 5.7.1: The institutional environment	*"Government will introduce an approach whereby a fixed percentage of the transfers by STI-intensive departments to their entities is to be spent on raising science awareness."*
13	Science engagement	Policy intent 5.7.1: The institutional environment	*"Support for existing science centres will be sustained, and support packages will be developed to establish more strategically positioned science centres, including world-class national flagship science centres or museums. This will require private sector co-funding."*
13	Science engagement	Policy intent 5.7.1: The institutional environment	*"A national coordinator of science engagement in South Africa will be entrenched through legislation. A system-wide science engagement coordination model will be instituted, going beyond the DST and its entities, enabling the higher education sector, industry, research councils, science centres and other relevant stakeholders to collaborate in science engagement."*
13	Science engagement	Policy intent 4.2: Brand South Africa as an innovative country	*"The establishment of an agency to coordinate system-wide science engagement"…*

Table 6: Domain-specific evaluation questions and methodological parameters

D-EQ	Logic model dimension(s)	Information availability*	Mode(s) of information gathering
3.1	Inputs	Feasible	Case study
3.2	Inputs	Feasible	Case study
3.3	Inputs	Feasible	Case study
3.4	Inputs, Outputs	Feasible	Case study
3.5	Inputs	Feasible	Case study
4.1	Inputs	Feasible	Case study
4.2	Inputs	Feasible	Case study
4.3	Inputs	Feasible	Case study
4.4	Inputs	Feasible	Case study
4.5	Inputs	Feasible	Survey; case study
4.6	Inputs, Outputs	Feasible	Survey; case study
4.7	Inputs	Feasible	Survey; case study
4.8	Inputs	Feasible	Case study
4.9	Inputs	Feasible	Survey; case study
4.10	Inputs	Feasible	Survey; case study
4.11	Inputs	Feasible	Case study
4.12	Inputs	Feasible	Case study
4.13	Inputs	Feasible	Survey; case study
5.1	Inputs	Feasible	Case study
5.2	Inputs, Outputs	Available; feasible	Databases (government, other); survey
5.3	Inputs, Outputs	Available; feasible	Databases (government, other); survey
5.4	Inputs, Outputs, Impacts	Feasible	Case study
5.5	Inputs, Outputs, Impacts	Feasible	Survey; case study
5.6	Inputs	Feasible	Survey; case study
5.7	Inputs	Feasible	Case study
5.8	Inputs, Outputs	Feasible	Survey; case study
5.9	Inputs, Outputs	Feasible	Survey; case study
5.10	Inputs, Outputs	Feasible	Survey; case study
5.11	Inputs, Outputs	Feasible	Survey; case study
5.12	Inputs, Outputs	Feasible	Survey; case study
5.13	Inputs	Feasible	Case study
5.14	Inputs, Outputs	Feasible	Survey; case study
5.15	Inputs	Feasible	Databases (government, other)
5.16	Inputs, Outputs	Feasible	Case study
6.1	Inputs	Available; feasible	Databases (government, other); survey; case study
6.2	Inputs, Outputs	Feasible	Survey; case study
6.3	Inputs	Feasible	Survey; case study

** Provisional judgement by authors based on currently available information in reviewed indicators reports*

Collating the above information on the various D-EQs, **Table 6** provides a tentative overview in terms of where they fit into the Logic model. For those questions where the informational status is sufficiently clear, we indicate the (likely) information availability, and associated mode(s) of information-gathering that are deemed most appropriate for sustainable M&E activities. With regards to modes of information collection, the main categories are:

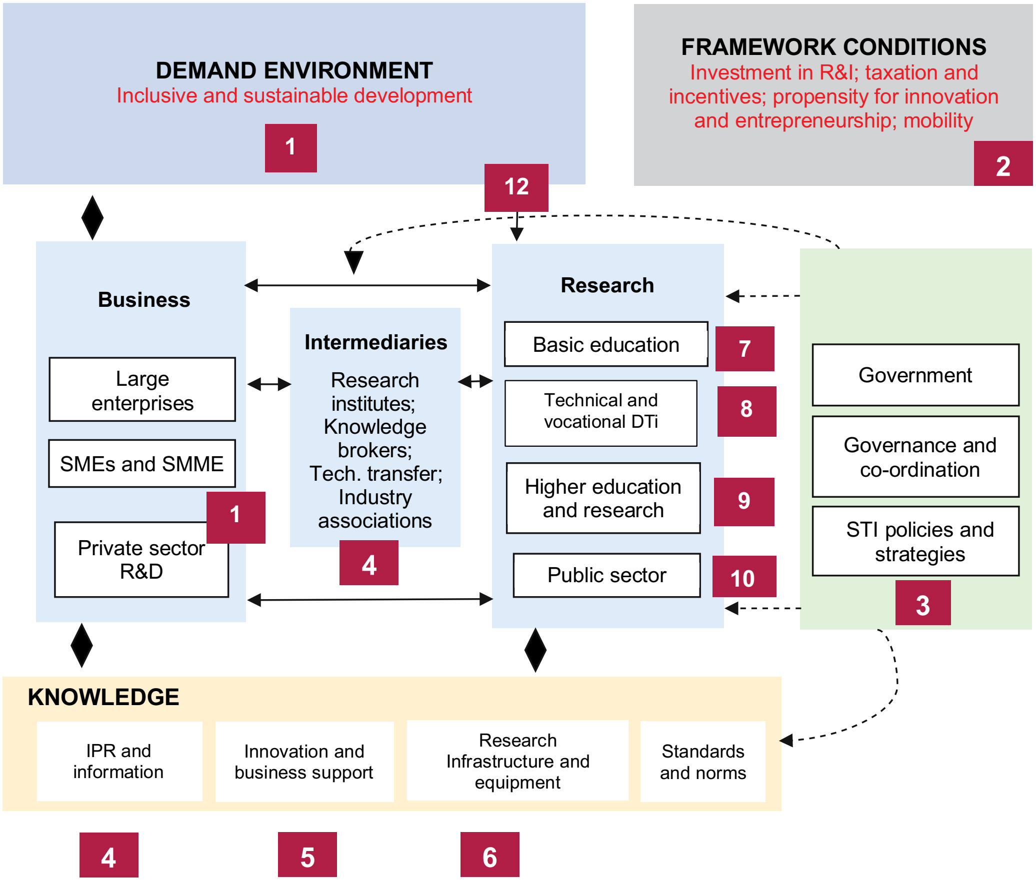
- Database - existing information systems and/or databases at government department /agency, or other available databases (either commercial or publicly accessible);
- Survey - conducting large-scale surveys and/or a series of interviews among relevant actors and stakeholders (either within or outside the government);
- Case study - conducting one or more dedicated, small-scale case studies;
- Unknown - to be determined or developed.

Having ascertained the M&E potential of feasibility of these D-EQs, we grouped the corresponding policy intents (see **Table 5**) into the following 12 aggregate-level 'STI policy areas':

1. Innovation for inclusive development;
2. Framework conditions;
3. Governance and co-ordination; monitoring and evaluation;
4. Knowledge infrastructure;
5. Support of SME and SOEs;
6. Research infrastructure;
7. Human resources development: basic education;
8. Human resources development: skills development;
9. Human resources development: general; engineering; PhD students; Postdoctoral fellows transformation;
10. R&D: interdisciplinary; cooperation;
11. Business R&D; technology development;
12. Science engagement.

The goal of this selection process is to arrive at a set of aggregate-level D-EQs that enable an evidence-based understanding about (progress towards to) desired changes in the STI system, and to identify the indicators and other information sources that need to be accessed or developed in order to attain that understanding. To test the coverage of these results of the TBE approach, we mapped these 12 policy areas onto the NSI model presented in section 2 (Figure 1). **Figure 17** builds on that Kuhlmann & Arnold model of NSI while incorporating the SA STI policy areas as they appear in the White Paper. The areas are projected onto the structure as red, numbered boxes. For illustrative reasons, the items listed in the two boxes at the top ('Demand Environment', and 'Framework Conditions') refer to those policy areas, thus replacing the original items in Figure 1.

Figure 17: National Innovation System structure - White Paper 'policy areas' superimposed



By mapping these policy intents to the different system component, we move a crucial step closer to developing a STI policy-driven ToC that is able to link STI system components to a various Logic model-driven M&E applications. The modified diagram draws attention to several general characteristics of the STI system that are relevant for developing an appropriately comprehensive M&E framework:

- The (demand) environment - within which the STI system, like other social systems, is embedded;
- The framework conditions - which need to be met for efficient and effective performance;
- The political system - which is the site of government (ministries and departments mandated to contribute to STI performance), as well as the required governance and policy arrangements;
- The knowledge infrastructure - which refers to the inputs (human resources, equipment and facilities), institutional connections and networks, and other support structures that contributes to system performance;
- The research and innovation 'performers' - both the public and private sector actors, whose main mission is to (co-)produce and distribute outputs, outcomes and impacts.

It is much easier to collect empirical information on inputs, than on medium-term outputs, let alone longer-term outcomes or impacts. Gathering information on STI processes and connections between STI actors also tends to be challenging. At this point it should be obvious that the input and output-related system characteristics - and associated policy domains, policy intents and evaluation questions - are typically assessed through quantitative (metrics-based) performance measures, such as the number of publications as a measure of output at systems, institutional, field and individual levels, whereas other processes, outcomes or impact-related properties of a NSI/STI system, such as collaboration and efficiency, are not as evidently captured in numbers only; here qualitative (narrative-based) performance indicators should also provide helpful information.

6.3 System evaluation questions and an outline for the M&E Framework

Thus far we have unpacked the policy intents in the White Paper and mapped them, as areas of evaluation questions, to components of the NSI/STI system. In doing so we have taken the overall STI system for granted and developed the outline of an M&E framework for the individual policy domains and priorities. One could also make an argument for a unitary 'system-wide' national approach to R&D priorities, which could be explicitly addressed in the context of a proposed framework. The required policy framework should align different actors and research organisations towards a common goal and STI focus (such as Inclusive Development).

Any comprehensive framework will also need to incorporate information with regards to relevant system-level patterns and trends such as: human mobility (inflows and outflows of students or highly qualified personnel); international research cooperation and infrastructures (university networks and joint research facilities); imports and exports of technology-embedded innovations and equipment and foreign direct investments by firms. The degree of the openness and internationalisation is an important structural feature that should be captured with key performance indicators.

These overarching issues have not been addressed. The White Paper further itemises (on p. 28) a few of those issues, and explicitly addresses the need for performance measures and indicators. *"This framework will include both quantitative and qualitative measures, as well as benchmarks relative to the rest of the world, covering at least the following:*

- *Investments/inputs into the NSI (funding sources and spending, people, infrastructure as well as partnerships/linkages) to indicate how the size, shape and strength of the NSI is evolving;*
- *The performance of the NSI (innovation activities, including R&D and outputs in terms of knowledge, products, technology transfer and applications);*
- *The behaviour of NSI actors;*
- *How the STI system is transforming the economy;*
- *Responsible Research and Innovation indicators;*
- *The systemic impact of sustained investment in specific programmes/fields;*
- *A composite South African Innovation Index will be developed that responds to the specific needs of the country, for example, in terms of skills development, inclusive economic growth and transformation. Furthermore, to ensure that research remains responsive, a system for evaluating research and reflecting on its impact will be developed and institutionalised."*

Continuing the trajectory of developing a TBE-approach to underpin the M&E framework, and addressing these items according to a Logic model type of structuring, the following non-exhaustive list of *'system evaluation questions'* (S-EQs) – based on the Kuhlmann and Arnold framework - emerges that refer to interrelated components and processes within the NSI/STI system:

- Is the rationale and structure of the STI system sufficiently aligned to user needs and policy objectives?
- How does the behaviour of institutional actors (including regulatory and governance structures) affect STI management and funding allocation processes, especially in terms of supporting effective coordination and cooperation?
- What is the effect of investments in funding and physical infrastructures on the composition and strength of the STI system, especially the sustained investments in specific programmes or targeted fields?

- What is the effect of investments in human capability development at the tertiary level on the STI system, especially the employability of university graduates and the quality of human resources in science?
- What is the effect of scientific and engineering research on technological development and innovation, especially in terms of effective knowledge transfer and utilisation?
- Which R&D and innovation outputs should be prioritised to boost performance of the STI system, especially in terms of strengthening the national science-innovation ecosystem and boosting innovation-led economic competitiveness?
- How do those R&D and innovation outputs enable the creation of valuable socio-economic outcomes and impacts, especially on business creation and enhanced employment levels, economic transformation and the Sustainable Development Goals?
- Are there sufficient incentives in place to assist businesses to become more productive and competitive, notably by importing and applying new, innovative technologies.

Needless to say that these S-EQ's should always be read in relation to D-EQ's. The difference is one of perspective: where the D-EQ's address evaluations issues 'inside' the STI system ordered according to STI domains or policy areas, the S-EQ's address evaluation issues about the STI system in its entirety and also within the larger national settings as well as international and the global contexts.

Figure 12 exhibits a diagram of such an 'ecosystem' M&E framework, which should not be confined to the many policy intents in the White Paper. Such a framework should, in an important sense, transcend specific policy intents and subsequent strategies. A comprehensive review of the South African NSI/STI system not only needs to be driven by policy considerations and evaluation questions, it also needs to be appropriately contextualised.. In line with the need to embracing dynamic and ever-changing complexity in such systems, some M&E applications will need to move beyond addressing STI activities, outputs and impacts as a rational, ordered and linear process, and should therefore transcend the linear 'input-output-outcome-impact' Logic model approaches. By applying a more system-wide 'configurational' M&E approach, which combines structural and inter-relational data; analysed in combination rather than in isolation - may prove more effective in showing how a range of STI variables affect inequality in the higher education, boost socio-economic transformation, or support innovation-driven business sector competitiveness.

The evaluation challenge lies in how to assess the overall performance of the system and its high-priority 'key' components. Given the complex, dynamic connections between the components, any evaluation will require a sophisticated, tailored approach. The units of evaluation will differ by time frame and different methodologies will be required at various stages. While some results will be easy to identify and assess within a short span of time (for example STI funding outlays), some impacts may take many years to materialise before they can be evaluated. Monitoring of processes should be incorporated in evaluation designs.

This outline of an M&E framework remains 'experimental' for now, as the final Decadal Plan should include more specific operationalisations of policy intents, as well as further clarification of expected outputs, outcomes and impacts. These changes will necessitate revisiting the underlying models and the framework itself. Irrespective of the framework's final structure and content, it will critically hinge on multi-method/multi-source approaches and will involve 'qualitative' information sources (such as programme reviews, system-wide audits, OECD reviews) as well as measurements and 'quantitative' indicators.

Section 7

Implementation

7.1 Key questions

Further elaboration and implementation of the M&E framework's outline should be guided by a series of 'framework implementation questions' that address its functionality and aims:

- Which dimensions and general properties of the system should be subjected to M&E? Which system-level components and entities should be targeted? At what lower levels of the STI system should M&E activities be undertaken?
- What are the 'qualitative' information and 'quantitative' data requirements to ensure effective M&E? Which sources of information should be assembled? Which performance indicators are crucial? Which ones are missing and should be developed?
- How should the M&E system be organised, embedded and implemented? When and how often should M&E studies be conducted? Which M&E methods should be employed, and by which M&E organisations?

The following sub-sections provide further reflections to help address these implementation questions.

7.2 System-level M&E: White Paper on Science, Technology and Innovation

A major input to the M&E framework is the *"White Paper on Science, Technology and Innovation: Science, technology and innovation enabling inclusive and sustainable South African development in a changing world"* (Department of Science and Technology, 2019). The document stresses the need for STI investments and more effective deployment in the pursuit of societal transformation, economic development, and greater inclusivity within the STI system[16]. The White Paper promotes a wide range of objective and measures to enhance the STI system's effectiveness, mainly by grasping opportunities in SA and worldwide STI trends (such as 'Industry 4.0'), building on prior successful initiatives, and offering some new approaches. The White Paper contains a very wide range of policy objectives, but is strongly focused on initiatives and 'soft instruments' with regards to the objective 'policy coherence and coordination' (Walwyn & Cloete, 2018)[17]. Other frequently-mentioned objectives fall under the categories of 'enhanced economic growth', 'enabling innovation environment', 'improved STI funding regimes' and 'expanded STI system and research enterprise'. Across all objectives, most of the policy instruments are related to either funding allocation, intra-governmental coordination, or planning and consultation. Issues of M&E are mentioned mainly with regards to the 'policy coherence and coordination' objective.

Our review of past evaluations and reviews (see subsection 2.5) has shown that various actors in the system, such as the DST, NRF, NACI, CHE and ASSAf have in the past commissioned and continue to commission, co-ordinate and/or undertake M&E studies. In the White Paper (Chapter 3, paragraph 6) the importance of upgrading the national M&E capacity (linked to policy capacity) of the NSI is made explicit:

3.6.1 Policy intent: Upgrade the M&E and policy capacity of the NSI

> *Agenda-setting and oversight of the NSI require effective monitoring and evaluation (M&E). Policy implementation needs to be improved by monitoring the progress of initiatives and assessing their impact to enable early corrective action. An effective M&E system will keep all stakeholders informed about what is and is not working. Processes need to be established to ensure that M&E information feeds into policy development and planning.*

Under the same heading, it is clearly stated that NACI will be reconfigured to act as the national STI M&E institution:

[16] *For the sake of simplicity and consistency, from here on we will refer in our texts as much as possible to the overarching concept of 'STI system' rather than the 'National Innovation System' (NSI) which is used extensively in the White Paper.*

[17] *Walwyn, D. & Cloete, L. (2018). Draft White Paper on Science, technology and Innovation neglects to prioritise issues of performance and human capacity, South African Journal of Science, 114 (11/12), Art. #5679.*

3.6.2 Institutionalising M&E for the NSI

> *NACI will be reconfigured to act as the national STI M&E institution, charged with analysing STI information and undertaking work to inform government planning on STI.*
>
> *Good performance information forms the bedrock of any effective M&E system. NACI will therefore implement knowledge management systems to enhance the analysis of NSI performance and support evaluation work informing strategies. In this, NACI will draw on the work of existing specialist centres collecting STI-related information. Existing institutional arrangements for data collection (e.g. innovation and R&D surveys) will be maintained and strengthened and, where necessary, expanded.*

In addition, DPME is also specifically mentioned in the context of expanding the M&E skills base in the country.

3.6.3 Skills for M&E in the NSI

> *The DST and the Department of Planning, Monitoring and Evaluation will cooperate with the higher education sector to expand the STI-related M&E skills base of the NSI.*

And finally, as far as the development and implementation of the M&E framework (presented here) is concerned, the following is stated in the White Paper:

3.6.4 New M&E framework for the NSI

> *South Africa will intensify its work on international STI measurement guidelines. Particular attention will be given to the Sustainable Development Goals, innovation for inclusive development, and the NDP objectives.*
>
> *NACI will convene a high-level forum to develop a framework of indicators to monitor South Africa's NSI performance (see box below). The DST will work with NACI, the DPME and the National Treasury to ensure that the framework delivers actionable and comparable information that can inform the management and funding of NSI initiatives.*

It is clear from these extracts from the White Paper that the Department of Science and Innovation is serious in expanding and institutionalising the current M&E infrastructure and capabilities as these relate to the STI system. However, further clarity is still required on many of the issues raised in the paragraphs above. We discuss these issues in more detail below.

7.3 Lower-level M&E: STI system components, domains and programmes

The SA STI system has a rich history of reviews and evaluations at all levels of the system (see **Table 1** in section 1.2). These reviews and evaluations often lack comparability. They are more like disconnected perspectives of a complex STI system, rather than different windows onto a 'panoramic view' of the system's landscape. A transparent and effective system-wide management of the M&E framework, and implementation across a variety of levels and activities, requires a certain degree of standardisation in terms of methodology and conceptual frameworks. Such a M&E framework should provide the main grid for mapping the system's inner workings.

Any such a M&E framework, designed for multi-level applications across that system, will also have to accommodate performance assessments of organisations and institutional entities with that system. These assessments of such 'system components', such as the series of national institutional reviews, will have to be sufficiently aligned with general requirements and analytical parameters of that M&E framework: these reviews should be based on a ToC and Logic model that is derived from the overarching, systems-level framework; the selected performance indicators should be aligned to, and 'interoperable' with, similar indicators at higher or lower levels in the M&E framework; the information sources should be identical or as closely linked as possible; the definitions of key concepts should be identical; the same methodological standards should be applied, etc.

The same alignment principle applies to M&E applications at the level of 'system domains', such as institutional or industrial (sub) sectors; fields of science and technology areas.

Where the White Paper mainly addresses system-level policy issues, the resulting 'system interventions' tend to materialise as dedicated initiatives targeted at specific components and domains. M&E of these 'programmes' should also be conducted in a way that complies, as much as possible, with the M&E framework requirements and parameters.

7.4 Who will own the M&E framework?

The White Paper specifies a role for NACI in the South African M&E system. What does 'reconfiguring' NACI mean in practice? Different possibilities can be imagined:

- NACI creates a new in-house unit that is dedicated to M&E and specifically implementing the M&E framework (if adopted);
- NACI establishes a consortium-like institution (bringing together various data producers and research entities) that can manage the implementation of the M&E framework;
- NACI assumes an oversight (liaison) role with an external agency (SA STI M&E Centre/ Observatory) that assumes the responsibility of managing the implementation of the M&E framework.

What does it mean that NACI will be charged with 'analysing STI information and undertaking work to inform government planning on STI'? This statement can be interpreted in a number of different ways:

- NACI expands its current analytical and research capacity to perform this function on its own;
- NACI expands its current analytical and research capacity to perform this function but in collaboration with external agencies and research centres in a structured (but virtual) manner (as if often found in a STI Observatory);
- NACI expands its current analytical and research capacity to perform this function but outsources/ commissions ad hoc work to external research centres and consultants.[18]

Next, what does it mean when the White Paper states that *'DST and the Department of Planning, Monitoring and Evaluation will cooperate with the higher education sector to expand the STI-related M&E skills base of the NSI'?* This statement, surprisingly, makes no mention of NACI's role and even more important any involvement by the NRF. It is not clear why DST and DPME would be seen as the main agencies to set up some co-operation agreement with universities to expand STI-related M&E skills? There is currently only one centre in the country (CREST) that has an accredited programme that focuses on Research Evaluation specifically. If this co-operation entails providing funding support for both accredited programmes and short course in R&D evaluation, this capacity needs to be recognised.

In addition to the questions that flow from statements made in the White Paper, the main question of this section ("Who owns the M&E framework?") speaks to a number of other issues and challenges:

[18] *Note: options b and c are not mutually exclusive.*

- To avoid unnecessary contestation about the framework and its implementation, it is crucial that (a) it is clarified what the status (authority) of this framework is if it is housed at NACI; and (b) even it is accepted that this framework is 'owned' by NACI, what its relationship with other M&E activities and actors in the system will be.
- It is essential to avoid a situation where the implementation of the framework is fragmented and as such is scattered in different components across the system. The framework must have integrity and clear authority. Its implementation, though, can be de-composed into logical units that are then managed in a decentralised manner by different actors.

7.5 Whose interests need to be reflected in the framework?

The White Paper's views on such a new M&E framework, displayed on page 28 of the document, specifies some of the proposed elements and performance measures to be included in that framework. There are a number of stakeholder groupings that would claim a direct interest in the framework – in terms of coverage and contents, as well as its analytical power and structuring capacity.

We can identify at least the following categories:

- The actors in the public sector that have as their missions to oversee or commission monitoring and evaluation reports (Presidency, Treasury, Parliamentary Portfolio Committee and DPME);
- The key state and parastatal actors in the STI system: DST, NRF, dti, DHET, CHE and so on;
- National agencies that already gather M&E data (e.g. CESTii);
- STI-active organisations (universities, government research labs, science councils, national research facilities, science and innovation parks, etc.);
- Other actors (NGOs, business enterprises, organised labour, etc.).

7.6 Who will implement the framework?

The M&E framework design should minimise the risk of adopting a wrong ToC, selecting inappropriate indicators or implementation plans. Design failures might lead to sub-optimal M&E practices, introduce misguided performance incentives, or incentivise inappropriate behaviour, unintended outputs or negative impacts on the STI system.

Working towards an operational 'M&E system' that will become applied in due course, the next steps (if the underpinning M&E framework is adopted) will be to develop a detailed and feasible implementation plan. Once this plan is adopted, which department and/or agency will implement the framework? The answer to this question will – evidently – be determined by the answer to the first question above: Who owns the framework? An implementation plan would typically include reference to the following five steps:

1. Specification in each case of the commissioning and implementing agencies for specific components of the M&E framework and the resources required for such activities. The implementation plan must be very clear about the respective authorities of those who may commission evaluations and those agencies (government and outside government) that will be tasked with conducting such evaluations.
2. Populating the listed indicator categories with indicators which are accompanied by appropriate technical descriptions to ensure consistency in application across different studies.
3. Populating the indicators with the required information and data depending on availability of existing sources and the feasibility of creating new sources.

4. Specification of the frequency of the evaluation and monitoring activities to be done. Evaluations (or reviews) of components of the SA STI should in some cases be done on a regular basis and in other cases on ad-hoc bases depending on contextual demands. As an illustration of what the plan may indicate, we would suggest the following:

    a. System-wide reviews be undertaken in five-year cycles (to be synchronised with national institutional reviews);

    b. Domain-specific reviews be undertaken in three-year cycles (to be synchronised with strategic goals and outcomes of interventions derived from the White Paper and other relevant policy documents;

    c. Benchmarking studies (including the publication of the SA STI Scoreboard and SA STI Index) be undertaken every two or three years. We believe that a more frequent benchmarking report (annually) is neither required nor desirable. Changes at the system-level are rarely as dramatic and revolutionary as to manifest itself in annual indicator reports.

5. Discussion of the dissemination and use of the evaluation findings of such studies. It is essential that a proper ‘uptake and evaluation use’ strategy be developed as part of the implementation plan. Anecdotal evidence suggests low uptake and follow-up regarding the findings and recommendations of many evaluations and reviews done in the country over the past two decades. The implementation plan should, therefore, include recommendations regarding the categories of users and use, modalities of documenting learnings from evaluation and monitoring studies (systematic reviews, evaluation and policy briefs).

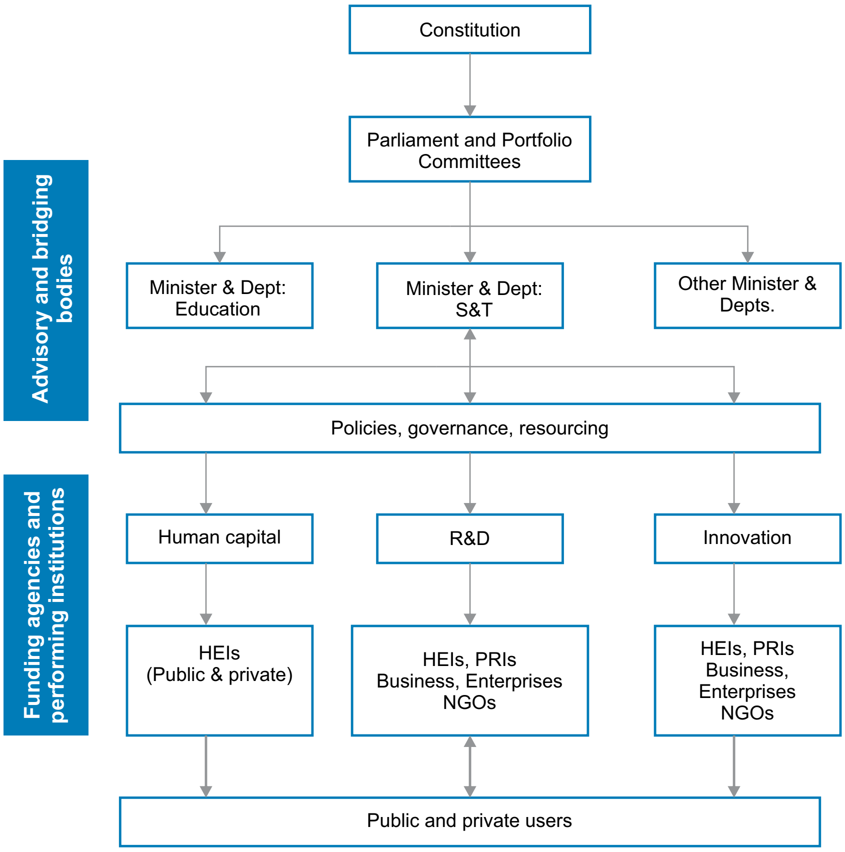
Appendix 1

Historical context of the South African STI system: The STI and changing policy regimes

MICHAEL J. KAHN

Designing an M&E framework requires an understanding of the general context of the evaluation 'object'; in this case the socio-political and historical context of the SA STI system. Most post-1994 STI policy documents use the concept of a 'national system of innovation (NSI)' as point of reference. Graphical depictions of such systems want to be based on a grid of building blocks connected with straight lines or arrows that seek to show the relationships and hierarchies among the various institutional actors in such systems. These schemas convey the notion of an ordered system that in turn might imply that the system lends itself to coordination. An example of such a schema is shown as Figure A1.1.

Figure A1.1: Overall governance structure of the South African NSI (2006)

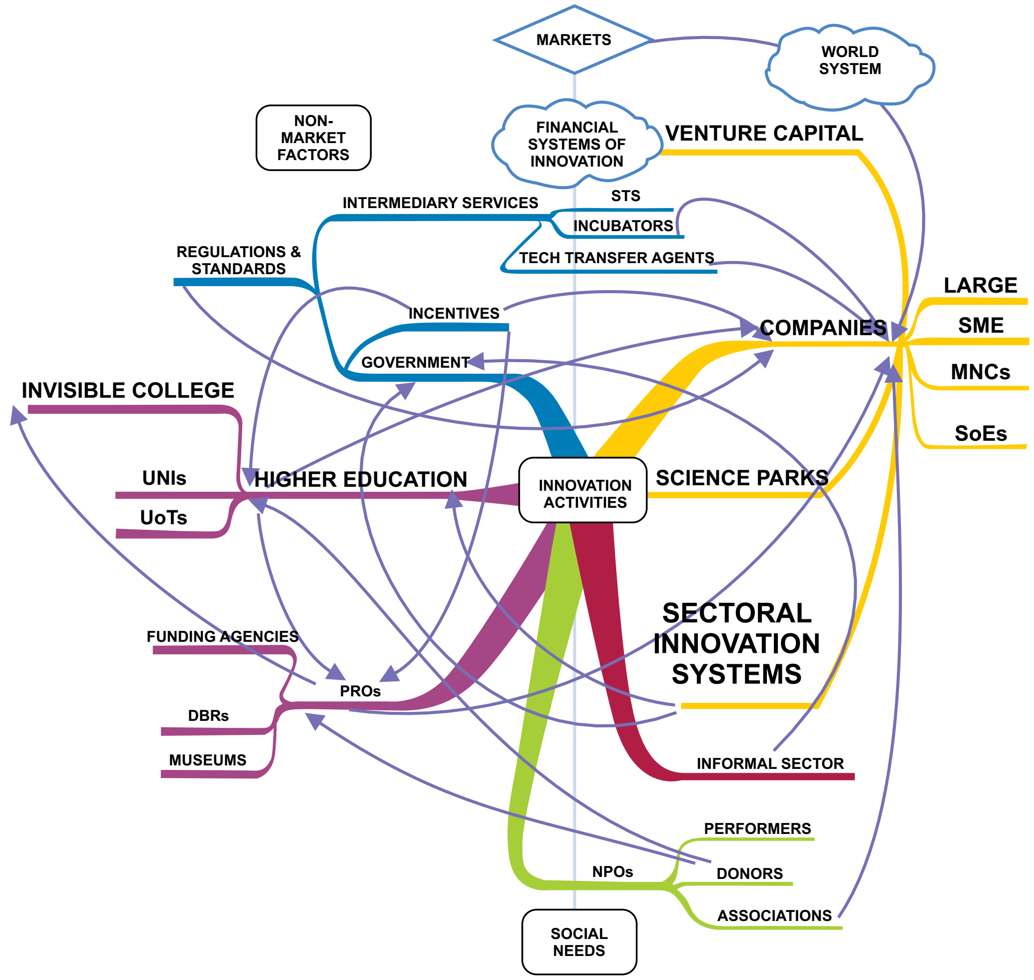


Source: NACI (2006)

Whether intended or not, this schema serves to reinforce the linear model thinking that this explicitly guided the work of most national departments and agencies (DACST/DST/NACI/NRF) through to the present. The linear model is ever-present, and constitutes the underlying theory of change that informs policy, instrument, project and funding decisions. This is clearly evident both in the National Research and Development Strategy of 2002 and the Ten-year innovation plan of 2008 (see discussion in Part Three below). According to Godin (2006), the durability of the linear model is widespread. The linear model allows for easy justification of investment in science.

It is suggested that a more realistic depiction of an NSI would attempt to recognise the non-linearity of interactions among the innovation actors; indeed, without such interactions, or linkages, or exchanges, the system does not really exist. Such a depiction is offered as **Figure A1.2** that shows some of the interactions characteristic of a functional innovation system. It serves to set any evaluand in the larger context, be this the system as a whole, being open to the world system, the invisible college of science, the mobility of innovation actors. Other local systems, such as that for financial innovation, might be appended. This schema might be termed the 'spaghetti model.' Bessant and Tidd (2011) have also referred to it as such.

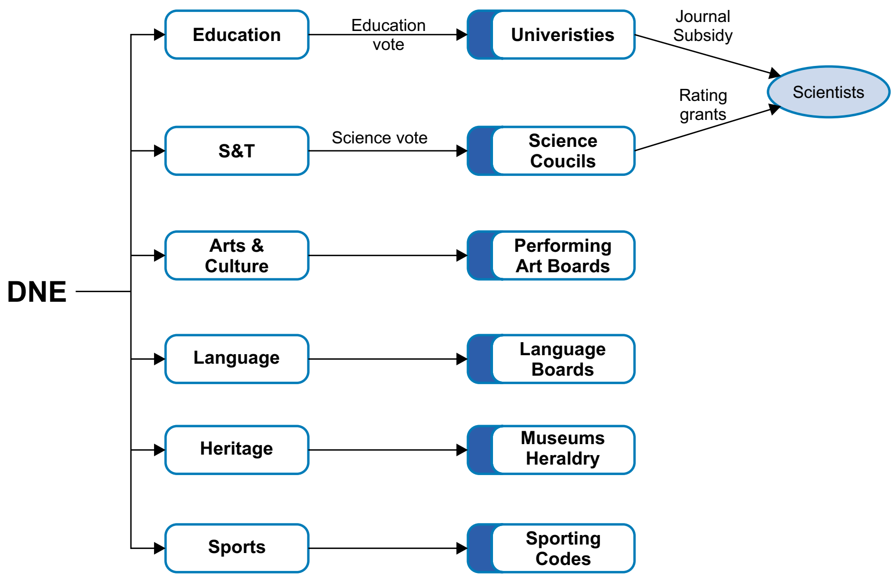
Figure A1.2: A non-linear visualisation of the NSI



Source: M. Kahn (2019)

NSI-thinking was adopted through the 1996 White Paper, and subsequently, as the department gained strength and confidence, reinforced more through discourse than in practice, since linear model thinking had captured the policy space. Prior to 1994, 'coordination' of the public sector component of the then NSI was vested in the Department of National Education (DNE) – see **Figure A1.3.**

Figure A1.3: Coordination via budgeting



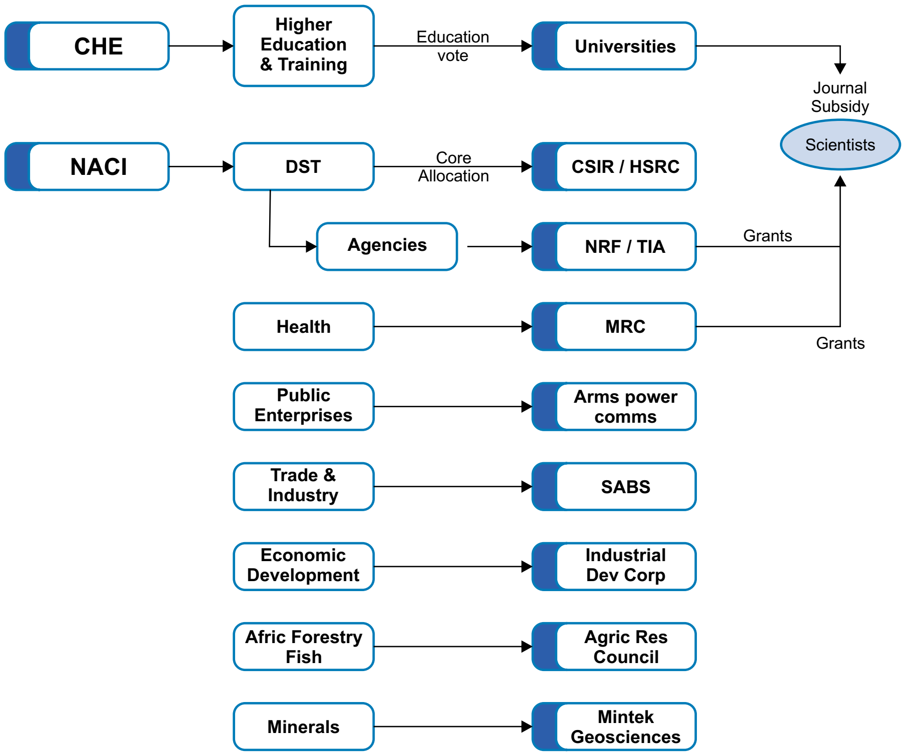
The DNE functioned as a central institution of the government of the day, with extensive policy oversight. Since parliamentary allocations flowed through DNE, a modicum of coordination was possible, though as argued elsewhere (Kahn, 2019; Mouton, 2014; Maharajh, 2011) the state adopted a hands-off approach to the then Republic of Science (the 'framework autonomy' policy adopted in 1988), provided that science came forward with the solutions required of the siege economy. A senior management echelon, some ten persons strong, carried out these functions.

The inception of a democratic government ushered in a process of legislative corrective action and modernisation, *inter alia* informed by the Bill of Rights, the Washington Consensus, accession to the World Trade Organization, and New Public Management (NPM). NPM in turn promoted a culture of performance measurement and accountability. The various instruments that embody these intents are as follows:

- Auditor-General Act 12 (1995);
- DACST White Paper on S&T (1996);
- SETI Reviews (1997);
- Performance measurement system for the Science Councils (1998);
- Employment Equity Act 55 (1998);
- Public Finance Management Act 1 (1999);
- Renewal of indicator measurement (HSRC 2002);
- Ministerial compacts (2009);
- Establishment of DPME (2010);
- Ministerial Review of the STI Landscape (2012);
- DST White Paper on STI (2019).

Taken at face value, the 2010 elevation of the M&E function to the Presidency, coupled with the set of Presidential-Ministerial Compacts, would seem to signal a deliberate policy of government openness and accountability. It is perhaps ironic to record that this is the very period during which overall governance failed. Constructing an M&E framework is necessarily informed by the above, but must also consider the evolution of the government structures that have a bearing on the NSI, and attempts to exercise coordination (**Figure A1.4**).

Figure A1.4: Decentralisation of control



Perhaps the most significant and durable outcomes of the post-1994 government as a whole - and the 1996 White Paper and 2002 National R&D Strategy in particular - were the creation of new institutions and reorganisation of pre-existing institutions. For the public sector of the NSI, these embraced:

(i) The creation of NACI, ASSAf, NSTF, NRF, the Innovation Fund, BRICS, TIA (including NIPMO);

(ii) The dismantling of the Science Vote;

(iii) Shift of CSIR from DTI to DST;

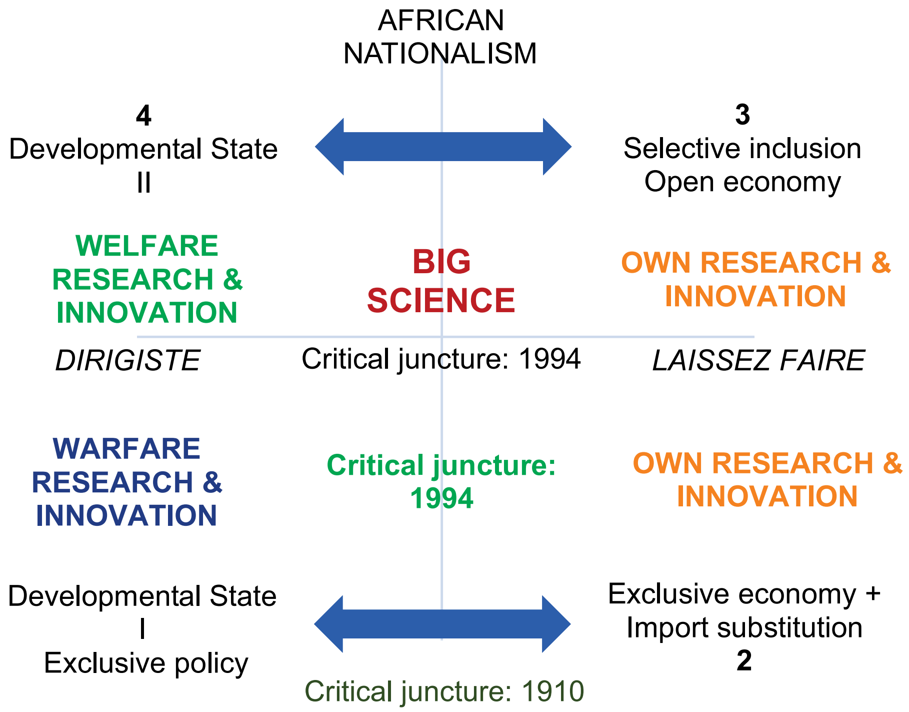
(iv) Multiple dismembering of Ministries.

These consequences are shown in the above figure. Arguably, far from improving the prospects for coordination, these actions render coordination less likely, and confer increased autonomy on the various institutions. A further consequence was the explosion of the senior management echelon from its original 10 to close to 300 staff.

In conclusion, it is useful to examine the changing roles of research and innovation in response to the demands of the times in South Africa, as summarised in **figure A1.5.** This four-quadrant schematic overview summarises the socio-political-economic changes that South Africa has traversed since the 1910 founding of the Union, and allows one to situate where research and innovation fit as defined by epoch on the vertical axis and economic policy on the horizontal. Three critical junctures are identified – that ushered in by Union, then apartheid, and more recently, constitutional democracy. Economic policy is characterised by two approaches, state-led (dirigiste) as opposed to market capitalism (laissez faire). The political crisis embodied in quadrant 1 during the construction of development state 1, leads to the NSI being deployed toward the war economy, while in parallel the needs of the market economy and the promotion of a sense of 'normality' allows for freedom of 'own' research and innovation. In the current epoch this division continues, even as development state 2 is built. Instead of 'warfare research and innovation' the emphasis shifts to Big Science with its prestige projects. 'Own' research and innovation continues.

There are parallels in these phenomena with the Frozen Revolution scenario of the Research and Technology Foresight (DACST, 1999). It might be possible to associate a distinct theory of change with each quadrant.

Figure A1.5: Changing role of research and innovation in South Africa (1910-present)



Source: M. Kahn (2019)

Over the past two decades, various forms of monitoring and evaluation activities have been institutionalised within the public sector in South Africa. In the words of Michael Power (1993), we can quite correctly claim that South Africa has also become a typical example of an 'audit' society. This is also true of the SA STI system where numerous evaluations and reviews - at different levels of the system – have been commissioned and conducted. These evaluations have been commissioned either as part of 'legal' or 'regulatory' imperatives or more informally on an ad-hoc basis as the need arises. The main bodies that have commissioned these studies are government departments (DST/DHET/*dti*), Science and HE agencies (NACI/NRF/CHE) or autonomous entities (ASSAf).

Appendix 2

Past evaluations and reviews of the South African STI system

NATIONAL (STI SYSTEM) REVIEWS

System-level evaluations and reviews

Year	Title	Evaluand	Commissioning agency	URL/Source
1998	*The System-wide Review Science, Engineering and Technology Institutions, a Report submitted to the Department of Arts, Culture, Science and Technology of the Government of South Africa, February 1998 (Updated June 1998)*	SETI's	DACST	https://www.gov.za/sites/default/files/gcis_document/201409/setreview0.pdf
1998	*Technology and Knowledge: Synthesis report of the National Research and Technology Audit. Pretoria: Department of Arts, Culture, Science and Technology.*	NSI	DACST	https://www.gov.za/sites/default/files/gcis_document/201409/nrtatech0.pdf
2006	*The South African National System of Innovation: Structures, policies and performance. Background report to the OECD Country Review of South Africa. Pretoria: National Advisory Council on Innovation.*	NSI	NACI/OECD	http://www.naci.org.za/wp-content/uploads/pdf/NACI%20Resources%20studies, %20reports%20and%20publications/2006/NACI%20Resources%20Studies%20etc.%20National%20system%20of%20innovation%202006.pdf
2007	*OECD Reviews of Innovation Policy : South Africa, ISBN-978-92-64-03823-3*	Innovation policy		https://read.oecd-ilibrary.org/science-and-technology/oecd-reviews-of-innovation-policy-south-africa-2007_9789264038240-en#page5
2012	*Final report of the Ministerial Review Committee on the Science, Technology and Innovation Landscape in South Africa, Staatskoerant, 31 Mei 2012, No. 35392, Notice 425 0f 2012*	STI Landscape	DST	https://www.gov.za/sites/default/files/gcis_document/201409/35392gen425a.pdf
2012	*Technology Trends: A Review of Technologies and Policies. (Pouris, A.)*	Techno-logy systems and policies	dti	http://www.dti.gov.za/industrial_development/docs/Final_Technology_Trends.pdf
2013	*Review of the State of the Science, Technology and Innovation System in South Africa*	STI System	DST	https://www.assaf.org.za/files/reports/8%20November%20NSI%20State%20of%20Science.pdf
2015	*Evaluation of the Indigenous Knowledge Systems Policy*	IKSP	DPME	N/A https://evaluations.dpme.gov.za/sites/EvaluationsHome/Evaluations/Forms/Evaluations%20View.aspx?RootFolder=%2Fsites%2FEvaluationsHome%2FEvaluations%2FImplementation%20Evaluation%20of%20Indigenous%20Knowledge%20System%20Policy&FolderCTID=0x012000E0CA669AE5F-03C4CB941A4CF655FB937003C4A39E-B1227914A97B3E202C80DF8B8&View={4AA-3BEC6-4E43-4468-9C18-E37F11F1DE8A}

Year	Title	Evaluand	Commissioning agency	URL/Source
2016	*Review of the White Paper on Science and Technology. (Walwyn, D.R.)*	STI Policy	NACI	http://www.naci.org.za/wp-content/uploads/2010/01/Review-of-the-White-Paper-on-Science-and-Technology.pdf
2016	*Synthesis Report: Review of the White Paper on Science and Technology and High Level Framing for a New Decadal Plan. (Walwyn, D.R.)*	STI Policy	NACI	http://www.naci.org.za/STIForesight2018/index.php/relevant-documents/policies-strategies-roadmaps-plans-sa/the-south-african-nsi
2017	*A Review of the South African Science, Technology and Innovation Institutional Landscape. Pretoria: Department of Science and Technology.*	STI Landscape	DST Ministerial Review Panel	https://www.dst.gov.za/images/2017/DST-institutional-review_Single-Page-WebVersion.pdf
2017	*Performance analysis of the NSI. (Kahn, M.)*	NSI	NACI	http://www.naci.org.za/STIForesight2018/index.php/relevant-documents/policies-strategies-roadmaps-plans-sa/the-south-african-nsi
2019	*The state of the SA research enterprise*	SA Research System	SciSTIP	https://www0.sun.ac.za/crest/wp-content/uploads/2019/08/state-of-the-South-African-research-enterprise.pdf

Reviews of national 'institutes' (Science councils, NACI, National facilities)

Year	Title	Evaluand	Commissioning Agency	URL/Source
2001	*SETI Review of MRC*	MRC	DACST	N/A
2002	*The Audit of the National Advisory Council on Innovation. Pretoria: National Advisory Council on Innovation.*	NACI		N/A
2003	*HSRC Institutional Review 2003*	HSRC	DST	www.hsrcpress.ac.za/books/human-sciences-research-council
2003	*SETI Review of CGS*	CGS	DST	N/A
2003	*SETI Review of CSIR*	CSIR	DST	N/A
2003	*Investigation into the implementation of SETI Review Recommendations. Foundation for Education Science & Technology*	FEST		http://www.naci.org.za/wp-content/uploads/2010/01/Investigations-in-to-the-Implementation-of-SETI-Reviews-Recomendations.pdf
2004	*Review of iTHEMBA Laboratory for Accelerator Based Sciences, 1-9 November 2004*	iTHEMBA	NRF	https://www.nrf.ac.za/sites/default/files/documents/2004%20iThemba%20LABS%20Review%20Report%20as%20part%20of%202005%20NRF%20Review%20%28web%29.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2004	*Institutional Review of the Council for Mineral Technology (MINTEK), October 2004*	MINTEK	DST	CREST
2004	*Review of the South African Astro-Geosciences Facilities of the NRF: Final report*	Ast0--Geo-sciences Facilities	NRF	https://www.nrf.ac.za/sites/default/files/documents/2004%20Astro-geosciences%20Facilities%20Review%20Report%20as%20part%20of%202005%20NRF%20review%20%20%28web%29.pdf
2004	*Review of the South African Institute for Aquatic Biodiversity (SAIAB)*	SAIAB	NRF	https://www.nrf.ac.za/sites/default/files/documents/2004%20South%20African%20Institute%20for%20Aquatic%20Biodiversity%20Review%20Report%20as%20part%20of%202005%20NRF%20review%20%28web%29.pdf
2005	*Review of the National Laser Centre Rental Pool Programme of the CSIR*	National Laser Rental Pool Programme	NCSIR	https://www.nrf.ac.za/sites/default/files/documents/2005%20National%20Laser%20Centre%20Rental%20Pool%20Programme%20Review%20Report%20%28website%29.pdf
2005	*Institutional Review of the National Research Foundation (NRF)*	NRF		https://www.nrf.ac.za/sites/default/files/documents/NRFInstitutionalReviewReport2005.pdf
2009	*SETI Review of CGS*	CGS	DST	N/A
2009	*SETI Review of CSIR*	CSIR	DST	N/A
2009	*International strategic review of CSIR*	CSIR		N/A
2010	*HSRC Institutional Review 2010*	HSRC	DST	
2010	*Final Report of the Panel for the 2010 SETI review of the Medical Research Council for the Department of Science and Technology (DST). Cape Town: MRC*	MRC	DST	http://www.samrc.ac.za/sites/default/files/attachments/2019-07-05/MRCSETIReview.pdf
2010	*NRF Institutional Review 2010 – Synthesis Report*	NRF	NRF	https://www.nrf.ac.za/sites/default/files/documents/Synthesis%20Review%20Report.pdf
2011	*AISA Institutional Review Report 2010/11*	AISA	DST	CREST Library
2014	*Final Report of the Panel for the 2014 review of the Medical Research Council for the Department of Science and Technology (DST). Cape Town: MRC*	MRF	DST	CREST Library
2015	*NRF Institutional Review 2015. Final Synthesis Report*	NRF	NRF	https://www.nrf.ac.za/sites/default/files/documents/2015%20NRF%20Institutional%20Review-Synthesis%20Report_0.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2015	*Five-year Institutional Review: Council for Geoscience. Pretoria*	CGS	DST	CREST Library
2015	*MINTEK Institutional Review*	MINTEK	DST	CREST Library
2015	*NRF Institutional Review-Synthesis Report*	NRF	NRF	https://www.nrf.ac.za/sites/default/files/documents/2015%20NRF%20Institutional%20Review-Synthesis%20Report_0.pdf
2016	*ASSAf Institutional Review Synthesis Report 2016*	ASSAf	DST	http://assaf.org.za/images/covers/ASSAf%20Institutional%20Review%20Synthesis%20Report%20final.pdf
2016	*Management response on Space Geodesy Review (June 2016)*	Space Geodesy review - HartRAO	NRF	https://www.nrf.ac.za/sites/default/files/documents/HartRAO%20Review%20management%20response%2019%20July%202016.pdf
2016	*Review of South African Space Geodesy Programme: Final Report (11 July 2016)*	Space Geodesy review - HartRAO	NRF	https://www.nrf.ac.za/sites/default/files/documents/Report_7_11%20%28final%29.pdf
2017	*Final report of the Panel for the 2017 Science, Engineering and Technology Institution (SETI) Review. SAMRC*	SA MRC	SAMRC	http://www.samrc.ac.za/sites/default/files/attachments/2019-07-05/SETIreviewSAMRC.pdf
2017	*Evaluation of the European Synchrotron Radiation Facility (ESRF)*	European Synchroton Radiation Facility	NRF	https://www.nrf.ac.za/sites/default/files/documents/2018%20Final%20ESRF%20Review%20Report%202017-12-07-133607.pdf
2018	*HSRC Institutional Review 2018*	HSRC	DST	Reviews of university research centres and institutes
2008	*Implementation evaluation of the African institute for mathematical sciences – South Africa programme*	AIMS	DST	CREST library
2009	*Review of DST/NRF Centre of Excellence for Biomedical TB Research (CBTBR)*	CBTBR	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20for%20Biomedical%20TB%20Research%20Review%20Report%20%28website%29.pdf
2009	*Review of the DST/NRF Centre for Invasion Biology*	CiB	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20for%20Invasion%20Biology%20Review%20Report%20%28website%29.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2009	*A review of the DST/NRF Centre of Excellence in Birds as Keys to Biodiversity Conservation*	Centre of Excellence in Birds as Keys to Biodiversity Conserva-tion	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20in%20Birds%20as%20Keys%20to%20Biodiversity%20Conservation%20Review%20Report%20%28website%29.pdf
2009	*External Review of the DST/NRF Centre of Excellence in Catalysis*	Centre of Excellence in Catalysis	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20in%20Catalysis%20Review%20Report%20%28website%29.pdf
2009	*Review of DST/NRF Centre of Excellence in Epidemiological Modelling and Analysis covering the period 2006 to 2008*	SACEMA	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20in%20Epidemiological%20Modelling%20and%20Analysis%20Review%20Report%20%28website%29.pdf
2009	*Review Report on the Centre of Excellence in Strong Materials*	Centre of Excellence in Strong Materials	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20in%20Strong%20Materials%20Review%20Report%20%28website%29.pdf
2009	*Review of DST/NRF Centre of Excellence Centre for Tree Health Biotechnology*	Centre of Excellence for Tree Health Bio-technology	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20CoE%20in%20Tree%20Health%20Biotechnology%20Review%20Report%20%28website%29.pdf
2014	*Review of the DST-NRF Applied Centre for Climate and Earth Systems Science (ACCESS)*	ACCESS	NRF	https://www.nrf.ac.za/sites/default/files/documents/2014%20DST-NRF%20Applied%20Centre%20for%20Climate%20and%20Earth%20Systems%20Science%20Review%20Report%20%28website%29.pdf
2014	*DST-NRF Applied Centre for Climate and Earth Systems Science (ACCESS) Response*	ACCESS	NRF	https://www.nrf.ac.za/sites/default/files/documents/2014%20DST-NRF%20Applied%20Centre%20for%20Climate%20and%20Earth%20Systems%20Science%20Management%20Response%20%28website%29.pdf

Sector-specific reviews

Year	Title	Evaluand	Commissioning Agency	URL/Source
2005	*HEQC Audit Reports*	HE	HEQC (CHE)	
2014	*Expenditure and Performance Review. EPR # 56206: Assessment of the Effective Partnering of Science Councils with the Private Sector. Report 1: Findings. Submitted by: RHIZOME MANAGEMENT SERVICES*	Science councils	National Treasury	https://www.gtac.gov.za/perdetail/16.2 Technical report.pdf (problems with opening on 17/Sep 2019)
2016	*Balancing Multiple Mandates: The Changing Role of Science Councils in South Africa. HSRC Press: Cape Town. (Kruss, B., Haupt, G., Tele, A., Ranchod, R.)*	Science Council (HSRC)	HSRC	CREST library and https://www.hsrcpress.ac.za/books/balancing-multiple-mandates
2016	*South African Higher Education Reviewed: Two decades of democracy*	HE	CHE	https://www.che.ac.za/media_and_publications/monitoring-and-evaluation/south-african-higher-education-reviewed-two-decades

Scientific field reviews

Year	Title	Evaluand	Commissioning Agency	URL/Source
2004	*Shaping the Future of Physics in South Africa. Report of the International Panel*	Physics	DST/ NRF/SAIP	https://www.nrf.ac.za/sites/default/files/documents/2004%20Shaping%20the%20Future%20of%20Physics%20in%20South%20Africa%20Review%20Report%20%28website%29.pdf
2007	*South Africa's Climate Change Technology Needs Assessment. Synthesis Report*	Climate Change	DST	https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TNR_CRE/e9067c6e3b97459989b2196f12155ad5/9ecba2a40fe-04948859b9930a40be9f7.pdf
2008	*Review of Mathematical Sciences Research at South African Higher Education Institutions: International Review Panel Report*	Mathematics	DST	https://www.nrf.ac.za/sites/default/files/documents/2008%20Mathematical%20Sciences%20Research%20Review%20Report%20%28website%29.pdf
2011	*Consensus Study on the State of the Humanities in South Africa: Status, prospects and strategies*	Humanities	ASSAf	https://www.assaf.org.za/files/2011/09/2011-Humanity-final-proof-11-August-2011.pdf
2012	*Water Resources of South Africa, 2012 Study (WR2012) Executive Summary*	Water resources	WRC	http://www.wrc.org.za/wp-content/uploads/mdocs/TT%20683%20web.pdf
2010	*Review of the NRF Biodiversity and environmental cluster as part of the NRF institutional review*	Biodiversity and environ-mental cluster	NRF	CREST Library

Year	Title	Evaluand	Commissioning Agency	URL/Source
2010	*Review of the NRF Astro-geosciences cluster as part of the NRF institutional review*	NCSIR	NRF	CREST Library
2010	*Review of the NRF Nuclear sciences cluster as part of the NRF institutional review*	Nuclear sciences cluster	NRF	CREST Library
2010	*Review of the NRF Science advancement cluster as part of the NRF institutional review*	Science advance-ment cluster	NRF	CREST Library
2010	*Review of the NRF Research and Innovation Support and Advancement cluster as part of the NRF institutional review – RISA*	R& Innovation Support cluster	NRF	CREST Library
2015	*Institutional Review of Biodiversity and Environmental Sciences Cluster Period 2009-2014*	Biodiversity and Environ-mental Cluster	NRF	CREST Library
2015	*Institutional Review of the National Research Foundation - Research and Innovation, Support and Advancement (RISA) Cluster*	RISA	NRF	https://www.nrf.ac.za/sites/default/files/documents/ RISA%20 Final%20Review%20Report%20%20August%202015%20 with%20correct%20weblinks.pdf
2014	*The State of Energy Research in South Africa*	Energy	ASSAf	https://assaf.org.za/files/2015/05/ASSAF-State-of-Energy-Research-Consensus-Report.pdf
2014	*The State of Green Technologies in South Africa*	Green technology	ASSAf	https://assaf.org.za/files/2015/05/8-Jan-2015-WEB-526305-ASSAF-Green-Tech-mail.pdf
2014	*South Africa's 20-year journey in water and sanitation research*	Water and sanitation	WRC	http://www.wrc.org.za/mdocs-posts/wrc20-final/
2015	*International Astronomical Union's Office of Astronomy for Development Review Report*	OAD	NRF	https://www.nrf.ac.za/sites/default/files/documents/2015%20 International%20Astronomical%20Union%27s%20Office%20 of%20Astronomy%20for%20Development%20Review%20 report%20%28website%29.pdf
2015	*Review of the National Research Foundation Astronomy Cluster*	Astronomy Cluster	NRF	https://www.nrf.ac.za/sites/default/files/documents/ FINAL_ ASTRONOMY_CLUSTER_REPORT_20%2010%202015.pdf
2015	*Review of the NRF Nuclear Sciences Cluster*	Nuclear sciences cluster	NRF	https://www.nrf.ac.za/sites/default/files/documents/NRF-Nuclear-Cluster-Review-6Aug2015-FINAL-REPORT.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2015	*Institutional Review of the Science advancement cluster SAASTA*	SAASTA	NRF	https://www.nrf.ac.za/sites/default/files/documents/SAASTA%20Review%20REPORT%20271115%20%20FINAL.pdf
2016	*Bibliometric analysis of astronomy research outputs*	Astronomy	CREST	CREST Library
2017	*State of Climate Change Science and Technology*	Climate Change	ASSAf	https://www.gov.za/sites/default/files/gcis_document/201708/assaf-state-climate-change.pdf
2019	*A scientometric assessment of Biological Sciences in South Africa*	Biological sciences	CREST	CREST Library
2019	*A scientometric assessment of Computer Science in South Africa*	Computer sciences	CREST	CREST Library
2019	*A scientometric assessment of Geological Sciences in South Africa*	Geological sciences	CREST	CREST Library
2019	*A scientometric assessment of Mathematics in South Africa*	Mathematics	CREST	CREST Library
2019	*A scientometric assessment of Physics in South Africa*	Physics	CREST	CREST Library
2019	*A scientometric assessment of Statistics in South Africa*	Statistics	CREST	CREST Library

Programme reviews

Science programmes (incl. research funding and capacity-building programmes)

Year	Title	Evaluand	Commissioning Agency	URL/Source
2001	Report on the evaluation of the National Research Foundation (NRF) Programmes directed at research and research capacity development at Technikons, 29 July to 8 August 2001	HBU programmes	NRF	https://www.nrf.ac.za/sites/default/files/documents/2001%20NRF%20Programmes%20directed%20at%20Research%20and%20Research%20Capacity%20Development%20at%20Technikons%20Review%20Report%20%28website%29.pdf
2001	Report on the evaluation of the NRF programmes directed at research and research capacity development at historical black universities (HBUs), 27 August to 6 September 2001	HBU programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/ 2001%20NRF%20Programmes%20directed%20at%20Research%20and%20Research%20Capacity%20Development%20at%20HBUs%20Review%20Report%20%28web%20site%29.pdf
2005	A Monitoring and Evaluation Framework to Benchmark the Performance of Women in the NSI: Final report to the SET4W reference group. Stellenbosch: Centre for Research on Evaluation, Science and Technology.	Women in NSI	CREST	http://www.naci.org.za/wp-content/uploads/pdf/NACI%20Resources%20studies, %20reports%20and%20publications/2005/NACI%20Resources%20Studies,%20etc.%20A%20Monitoring%20and%20Evaluation%20Framework%20to%20Benchmark%202005.pdf
2007	Review of the NRF Rating System; Synthesis report. (Auf der Heyde, T., Mouton, J.)	NRF Rating system	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Higher%20Education%20South%20Africa%20%28HESA%29%20-%20Review%20of%20NRF%20Evaluation%20and%20Rating%20System%20.pdf
2007	Review of the NRF System for the Evaluation and Rating of Individual Researchers	NRF rating System	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Findings%20and%20Recommendations%20by%20Review%20Steering%20Committee%20as%20part%20of%20HESA%20Review%20%28website%29.pdf
2007	An historical review and analysis of the NRF Rating System 1983-2005. (Sue Krige)	NRF rating system	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Historical%20Review%20and%20Analysis%20of%20Rating%20System-Study%20as%20part%20of%20HESA%20Review%20%28website%29.pdf
2007	The Focus Area Landscape Programme of the National Research Foundation: A review. (Marais, H.C.)	Focus Area Landscape Programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Focus%20Area%20Landscape%20Review%20Report%20%20%28website%29.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2007	Impact of the NRF Evaluation and Rating System: a review. (Marais, H.C.)	NRF rating system	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Impact%20of%20rating%20system%20on%20scholarly%20productivity%20of%20SA%20academics-Study%20as%20part%20of%20HESA%20review%20%28website%29.pdf
2007	Review of the Palaeontological Scientific Trust (PAST)	PAST	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Palaeontological%20Scientifc%20Trust%20Review%20Report%20and%20Management%20Response%20%28website%29.pdf
2007	Review of Processes Used to Manage the Rating of Individual Researchers. (Madikizela, M.)	Rating system	NRF	https://www.nrf.ac.za/sites/default/files/documents/2007%20Processes%20used%20to%20manage%20Rating%20System%20in%20past%20five%20years-Study%20as%20part%20of%20HESA%20review%20%28website%29.pdf
2009	Review of the DST/NRF Centre of Excellence (CoE) Programme	CoE Programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20Centres%20of%20Excellence%20Programme%20Review%20Report%20%28website%29.pdf
2009	The National Research Foundation Management Response to the Review of the Centres of Excellence programme	CoE Programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/2009%20DST-NRF%20Centres%20of%20Excellence%20Programme%20Management%20Response%20%28website%29.pdf
2011	Mid-Term Evaluation for BioFISA	BIOFISA	Ministry of Foreign Affairs of Finland	https://www.fcg.fi/eng/projects/?RefID=907
2011	Review of the first ten years of the National Science Week programme of the Department of Science and Technology	National Science Week	DST	https://evaluations.dpme.gov.za/evaluations/95
2012	Review of the National Astrophysics and Space Science Programme (NASSP) and the Multi-Wavelength Astronomy (MWLA) programme	NASSP and MWLA	NRF	https://www.nrf.ac.za/sites/default/files/documents/ 2012%20National%20Astrophysics%20and%20Space%20Science%20Programme%20and%20Multi-wavelength%20Astronomy%20Programme%20Management%20Response%20%28-website%29.pdf
2012	Five Year Review of the South African Research Chairs Initiative (SARChI)	SARChI programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/Review%20Report.pdf
2012	NRF Response to the Findings and Recommendations contained in the South African Research Chairs Initiative Review		NRF	https://www.nrf.ac.za/sites/default/files/documents/The%20management%20response.pdf

Year	Title	Evaluand	Commissioning Agency	URL/Source
2013	Review of the DST-NRF Centres of Excellence Programme 2013	COEs	NRF	CREST Library
2014	Review of the National Research Foundation managed Indigenous Knowledge Systems Programme	IKS programmes	NRF	https://www.nrf.ac.za/sites/default/files/documents/Report%20on%20the%20review%20of%20IKS%202014.pdf
2015	DST-NRF Review of the NRF Managed Bioinformatics and Functional Genomics (BFG) programme for the period 2009-2015	BFG programme	NRF	https://www.nrf.ac.za/sites/default/files/documents/2015%20NRF-Managed%20Bioinformatics%20and%20Functional%20Genomics%20Programme%20Review%20Report%20%28website%29.pdf
2015	Management response to the review of the Bioinformatics and Functional Genomics Funding Instrument (BFG)	BFG instrument	NRF	https://www.nrf.ac.za/sites/default/files/documents/2015%20NRF-Managed%20Bioinformatics%20and%20Functional%20Genomics%20Programme%20Management%20Response%20%28website%29.pdf
2015	Implementation and Impact Evaluation of the Technology and Human Resources for Industry Programme (THRIP)	THRIP	DTI / DPME	CREST Library
2017	Review of the F'SATI programme 2008-2015	F'SATI	NRF	https://www.nrf.ac.za/sites/default/files/documents/F%27SATI%20REVIEW%20REPORT-2017.pdf

Technology and innovation programme reviews

Year	Title	Evaluand	Agency	URL/Source
2012	THRIP Impact report	THRIP	NRF	N/A
2014	Impact evaluation of Support Programme for Industrial Innovation. Final evaluation report submitted to DPME by Genesis Analytics	SPII	DPME	http://www.thedti.gov.za/trade_investment/Evaluation/Genesis_Analytics_DPME_SPII_Evaluation24042014.pdf
2015	Implementation and Impact Evaluation of the Technology and Human Resources for Industry Programme (THRIP). Summary report	THRIP	DTI /DPME	https://www.dpme.gov.za/keyfocusareas/evaluationsSite/Pages/Reports.aspx

Appendix 3

The origins and development of TBE

LAUREN P. WILDSCHUT (CREST)

This appendix traces the roots of TBE and examine key contributions to its development. The discussion of the development of TBE has been divided into four key phases:[19]

1. The seeds of TBE (1909 - 1959);
2. The roots of TBE (1960 - 1979);
3. The establishment of TBE (1980 – 1999);
4. The current state of TBE (2000 – present).

These phases are not discreet and contributors to one period may certainly have contributed to the next, but the four phases provide a useful framework for a discussion of the different periods of development, and the nature of the various contributions. Before the discussion of the development can begin, the concepts of TBE and programme theory need to be unpacked.

"Black-box"[20] evaluation (Bickman, 2000; Chen, 2005b; Chen & Rossi, 1997; Stame, 2004, Weiss, 2007) is a term used to describe the practice of evaluating social interventions with a strong focus on the benefits accrued in a programme, with little attention paid to how those benefits are produced. This results in very little knowledge about the mechanisms that cause change. Black box evaluation, which occurs when the process of transformation in a programme is concealed through a lack of focus on the relationship between programme components, was very prevalent in the 1960s (but still occurs today). Chen & Rossi describe the result of black box evaluations in the following way:

> *... the outcomes of evaluation research often provide narrow and sometimes distorted understandings of programmes. It is not usually clear whether the recorded failures of programmes are due to the fact that the programmes were built on poor conceptual foundations, usually preposterous sets of "causal mechanisms"… or because treatments were set at such low dosage levels that they could not conceivably affect any outcomes … or because programmes were poorly implemented (Chen & Rossi, 1983:284).*

Later, Chen (1994:18) in criticism of black-box evaluation, stated that this kind of evaluation may "show a new drug to be capable of curing a disease without providing information on the underlying mechanisms of that cure, [but] physicians will have difficulty prescribing the new drug because the conditions under which the drug will work and the likelihood of negative side effects will not be known". This was primarily a criticism of the experimental tradition in evaluation (Campbell & Stanley, 1963), which was commonplace at the time. Chen emphasised the importance of understanding the 'underlying mechanisms' of change in interventions and promoted the idea of TBE as a means of extracting the set of cause-and-effect relationships in a programme.

TBE is thus an evaluation approach which opens up the 'black box' of the programme logic for scrutiny and is also referred to as 'glass box', 'white' or 'clear box' evaluation (Astbury & Leeuw 2010; Scriven 1994). Weiss (1997b:51) pointed out that evaluation needs to get 'inside the black box' but added that this should be done 'systematically'. Evaluations which go 'inside the black box' or utilise a programme's underlying theory are referred to in many different ways. The first published use of the term 'theory-based evaluation' was in 1975 by Carol Taylor Fitz-Gibbon and Lynn Lyons Morris in a four page contribution to Evaluation Comment[21]:

A theory-based evaluation of a programme is one which the selection of programme features to evaluate, is determined by an explicit conceptualisation of the programme in terms of a theory, a theory which attempts to explain how the programme produces the desired effects. (Fitz-Gibbon & Morris, 1975. Reprint 1996:177).

Chen and Rossi (1980) were the first to use the term 'theory-driven evaluation' while Bickman (1987), in the special edition of *New Directions for Program Evaluation* which focused on utilising programme theory in evaluation, in fact did not label this approach

19 Weiss (1997b) divides her discussion of TBE into three phases (past, present and future). Her delineation of phases assumes there was no contribution to TBE before Suchman.

20 Funnell and Rogers discuss the origins of the term "black-box" and describe its links in evaluation to the flight recorders used in aeroplanes. They also raise Patton's objection to the term due to its negative connotation and his suggestion that evaluators utilise the term "empty box, magic box or mystery box" (Patton in Funnell & Rogers, 2011:4). I have continued to utilise the term "black-box" as I think the nickname given for the original flight recorders (which are actually orange in colour) vividly conjure up a visual image of secrets hidden in a dark box.

21 A publication of The UCLA Center for the Study of Evaluation.

to evaluation as a separate type, but simply focused on the use of 'programme theory' in evaluation. Following on this landmark edition of the journal, the definitions and different meanings used to describe the approach multiplied with each practitioner or theorist discussing the approach. The following table shows some of the confusing array of terms found in evaluation literature which refer to evaluation that utilises programme theory:

Table A3.1: Some of the terms used to label evaluation utilising programme theory

TERM USED	SOURCE
Chains of reasoning	Torvatn (1999)
Impact pathway analysis	Douthwaite, Kuby, van de Fliert and Schulz (2003)
Logic analysis	Brousselle *et al.* (2007)
Outcomes hierarchies	Bennett (1975)
Program logic	Funnell (1997)
Program theory	Bickman (1987, 1996)
Program theory analysis	Brousselle *et al.* (2007)
Program theory-driven evaluation	Chen (2005a)
Program theory evaluation	Rogers (2000); Stufflebeam (2011); Brouselle & Champagne (2011)
Programme theory-driven evaluation science	Donaldson (2005)
Theory- based evaluation	Fitz-Gibbon & Morris (1975); Friedman (2001); Weiss (1995, 1997a)
Theory-driven evaluation	Bledsoe & Graham (2005); Chen (1990b); Chen & Rossi (1983); Sidani & Sechrest (1999); Turnbull (2002); Worthen (2001)
Theory-led	Molas-Gallart & Davies (2006)

Also cited in Funnell and Rogers (2011:23-24) are the terms: 'Causal chain' (Hall & O'Day, 1971); 'Causal map' (Montibeller & Belton, 2006); 'Intervention Framework' (Ministry of Health, NZ 2002), 'Intervention logic' (Nagarajan & Vanheukelen, 1997) and 'Intervention theory' (Argyris, 1970; Fishbein et al. 2001). Sometimes the terms listed in the table are used interchangeably, but in other cases authors have used slightly different terms usually to distinguish their own brand of evaluation that utilises programme theory. Weiss (1997b), and more recently Davidson (2006) and Astbury and Leeuw (2010), make the point that proponents and authors in the field of TBE need to be more careful in their use of terminology associated[22] with TBE.

This study utilises the popular Weiss term 'Theory-based evaluation' as the notion of evaluation being 'based' on theory or using theory as the foundation or starting point of the evaluation, seems most useful. The term is also broad enough to encapsulate the wide range of evaluations carried out under the banner of TBE to a greater degree than terms such as 'driven' or 'led'. Torvatn's definition of TBE is used for this study for the same purpose – it is broad enough to cover a wide range of evaluations that are labelled as TBE:

> *In short, programme theory is a model that describes the logic and context of the programme and enables the evaluator to check on programme progress and impact before the programme is conducted. A programme theory-driven evaluation is one where the evaluator constructs a programme theory and uses this theory as a guide in the evaluation process. (Torvatn, 1998:74).*

Rogers, in her later work (2008), also follows this generous, all-encompassing definition (which focuses on the notion of guidance) and is not as prescriptive as other definitions. Most definitions of TBE include the idea of surfacing the assumptions/theory/theories on which the programme is based and then using this to guide the evaluation (Bickman, 1990;

[22] *A discussion later on in this section deals with the various terms used to describe a programme theory or articulation of that theory.*

Birckmayer & Weiss, 2000; Brouselle & Champagne, 2011; Chen, 1990a; Chen & Rossi, 1983; Carvalho & White, 2004; Costner, 1989; Douthwaite et al., 2003; Fitz-Gibbon & Morris, 1975; Mercier et al., 2000; Rogers, 2000a; 2000b; 2007;2008; Sidani & Sechrest, 1999; Weiss, 1995; 1997a; 1998; 2001; Williams & Morris, 2009)[23].

Shadish, Cook and Campbell (2002) claim that most TBE approaches share three fundamental characteristics: (a) to explicate the theory of a treatment by detailing the expected relationships between inputs, processes, and short- and long-term outcomes (b) to measure all of the constructs in the theory and (c) to analyse the data to assess the extent to which the expected relationships actually occurred. Coryn et al. (2011) expand these three features of TBE into five: (a) theory formulation (b) theory-guided question formulation (c) theory-guided evaluation design, planning, and execution, (d) theory-guided construct measurement, and (e) causal description and causal explanation. Figure 3.1 is based on their description of TBE.

The five key elements of the TBE process are:

1. **Formulate a plausible programme theory**

   TBE is a form of evaluation that illuminates the set of cause-and-effect relationships in a programme. According to Coryn *et al*., 2011 this theory can be

   - Based on existing theory and research (e.g. social science);
   - Implicit i.e. based on the unarticulated assumptions and experience of programme staff;
   - Emergent i.e. developed from data collection (e.g. observations and interviews);
   - Developed by an evaluator or;
   - Integrated i.e. based on the best combination of all previous types of theories listed.

   These five varied sources of theory indicate that programme theory is “theory with a small t” (Chen & Rossi, 1997) rather than the type of theory developed in the natural or social sciences which is based on repeated testing and used for prediction. The first step of the TBE process, theory development, often involves the construction of a model to represent the programme theory.

2. **Formulate and prioritise evaluation questions**

   TBE utilises programme theory to develop evaluation questions, but the life cycle and evaluation purpose should also determine the process of prioritisation of evaluation questions.

3. **Use programme theory to guide evaluation**

   TBE should guide the focus of the evaluation, but time, budget and the proposed use of the evaluation will also play a role in decision regarding which elements of the programme and theory are focused on during the evaluation.

4. **Collect and analyse data focussing on programme theory and evaluation questions**

   TBE should result in the collection and analysis of data at critical points that are primarily determined by the programme theory, but also generally by evaluation questions (Birckmayer & Weiss, 2000; Weiss, 1995; Carvalho & White, 2004; Monroe et al., 2005; Torvatn, 1998)

5. **Test theory**

   TBE should systematically test the articulated theory (Astbury & Leeuw, 2010; Rogers et al., 2000; Torvatn, 1998; Weiss, 1972, 1995, 1997b, 1998, 2001) and indicate if a breakdown occurs at a particular point in the theory (Carvalho & White, 2004; Weiss, 1995).

[23] *Illustrative authors have been provided in the unpacking of TBE definitions as the number of authors including particular elements is so numerous.*

Other common features of TBE not covered in the Coryn et al. (2011) model are that TBE should distinguish between programme theory and implementation theory (Bickman, 1987; 1990; Chen & Rossi, 1992; Lipsey, 1990, 1993; Weiss, 1995), and that evaluation should not be method driven (Donaldson & Gooler, 2003; Torvatn, 1998). A discussion of programme theory and its features follows.

Table A3.1: Phase 1: The seeds of TBE (1909 – 1959)

Date[24]	Concept	Focus	Contributor	Link to TBE
1911	Scientific management and job analysis	Business and management	Taylor	Focus on key components of a process (not only outputs) and their relationships for maximum efficiency
1913	Activity Analysis	Education - curriculum development	Bobbitt	Focus on key components and sequencing of processes
1909	Scientific curriculum – modified Activity Analysis	Education -curriculum development	Charters	Backward mapping of causal paths from outcomes to activities
1930	Performance-objectives congruence	Education- curriculum development	Tyler	Focused on hypotheses behind curriculum. Participation of stakeholders.
1942	Seven-Step Procedure to Evaluation	Education – curriculum construction	Tyler	Testing theory
1956	Objectives Hierarchies	Education – curriculum development	Bloom	Unpacking the black-box of student thinking
1956	Evaluation of technical and accomplishment	Health	MacMahon	Testing of a hypothesis of the programme
1956	Systems Dynamics Modelling	Management	Forrester	Development of causal maps to depict causal assumptions and graphics to represent cause and effect
1959	Four Levels of Learning	Evaluation	Kirkpatrick	Articulation of process and the use of a framework to both implement and evaluate the process

[24] *The date column in the table refers to the first published work of the contributor relevant to the link of TBE. The dates are not in absolute chronological order; rather they follow a content chronology, i.e. how one author built on the ideas of his/her predecessor.*

Table A3.2: Phase 2: The roots of TBE (1960 - 1979)

Date[25]	Concept	Focus	Contributor	Link to TBE
1962	Representations of objective hierarchies as flow charts	Education – learner performance	Gagne	Testing theory Multiple pathways
1967	Chain of Objectives and the importance of testing 'black box' of social programmes	Evaluation	Suchman	Open system in PT Emphasis on use of stats for PT
1967	Model of Antecedents, Transactions and Outcomes.	Education	Stake	Tabular format of model Comparison against criteria
1971	Program Theory becomes an essential pre-evaluation step in any discrepancy evaluation	Evaluation	Provus	Development of Logic model Comparison against criteria and other programmes
1971	CIPP model	Evaluation	Stufflebeam	Focus on programme strategy Model components
1972	Theory-Based Evaluation first described	Evaluation	Weiss	Scholarship: Theoretical content Description of process Pathway diagrams
1973	Evaluation university programmes	Evaluation	University of Illinois, Stanford University, Boston College, UCLA, University of Minnesota, and Western Michigan University	
1975	Term 'Theory based evaluation' labelled	Evaluation	Fitz-Gibbon and Morris	TBE labelled
1975	Hierarchy of outcomes	Evaluation	Bennett	Early generic Programme Theory developed
1975	Professional association for evaluators	Evaluation	Evaluation Network	Forum to debate and advocate TBE
1976	Professional association for evaluators	Evaluation	Evaluation Research Society	Forum to debate and advocate TBE

[25] The date column in the table refers to the first published work of the contributor relevant to the link of TBE. The dates are not in absolute chronological order rather they follow a content chronology i.e. how one author built on the ideas of his/her predecessor.

Table A3.3: The establishment of TBE (1980 -1999)

Date[26]	Concept	Contributor	Link to TBE
1980	Theory-Driven Evaluation	Chen and Rossi	A range of publications in the 1980s on notion of theory and processes for TDE
1983	Evaluability assessment	Wholey	Checklist and programme theory models
1986	American Evaluation Association Founded	American Evaluation Association	Forum allows for discussion on evaluation approaches
1987	Bickman edits first volume of New Directions for Programme Evaluation	Bickman	Publication focused entirely on programme theory
1989	Chen guest edits for a special issue of Evaluation and Programme Planning	Chen	Publication focuses on TDE, validity and barriers
1990	Bickman edits another volume of New Directions for Programme Evaluation	Bickman	Publication focuses on advances in programme theory
1990	Theory-Driven Evaluation	Chen	First book solely on TDE –Distinction between normative and causative evaluation and six domain theories defined
1997	Realistic Evaluation	Pawson and Tilley	A particular brand of TBE is advocated
1997	User-Focused Approach to Evaluation	Patton	Acknowledges the role of Chen in development of TBE and the value of TBE
1999	Programme Evaluation: A Systematic Approach	Rossi, Freeman and Lipsey	First time a chapter on programme theory and Logic models added to this seminal work

26 *The date column in the table refers to the first published work of the contributor relevant to the link of TBE. The dates are not in absolute chronological order rather they follow a content chronology i.e. how one author built on the ideas of his/her predecessor.*

Appendix 4

Evaluation questions extracted from White Paper

The phrases referring to areas of proposed policy actions are underlined. The overview is sequentially organised per chapter in the White Paper and EQs are numbered according to their mentioning in each chapter.

Chapter 3: A coherent, inclusive National System of Innovation

EQ 3.1 (Policy intent 3.2: Improve inclusion and build more linkages across the NSI):

> *Formal mechanisms (e.g. sector-based planning instruments) will also be institutionalised to improve interaction among actors. Furthermore, where necessary, effort will be directed at strengthening collaborative R&D instruments such as Centres of Competence, and Sector Innovation Funds.*

EQ 3.2 (Policy intent 3.3.6: Horizontal and sector/thematic coordination):

> *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 interministerial 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. Sector science councils will continue to report to their line departments. This will allow councils to conduct research and promote innovation to further modernise and enhance the competitiveness of relevant sectors. The science councils will increasingly help the country to translate research into products and services, demonstrate the use of knowledge in transforming society, and inform government policy related to their respective sectors.*

EQ 3.3 (Policy intent 3.4: Strengthen the governance of public NSI institutions):

> *Consequently, under the guidance of the DST, such a policy framework will be developed to describe the purpose, functions and governance of Public Research Institutions 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 Public Research Institutions 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.*
>
> *As the mandates of Public Research Institutions are refined according to this policy framework, an appropriate evaluation framework will be put in place to enable objective assessment of their efficiency levels. This will be a prelude to interventions to improve productivity across the focus areas of Public Research Institutions.*
>
> *The evaluation criteria will include requirements for expanding collaboration with civil society, industry and international partners (e.g. to establish international research institutes). In particular, the requirement to maintain and expand the science base will be incorporated. The ambitions underpinning this White Paper – excellence, inclusion, partnerships and pan-African collaboration – will be built into the evaluation framework.*

EQ 3.4 (Policy intent 3.5.2: Expansion of the scientific knowledge base of the NSI):

> *The DST and DHET will collaborate in implementing overarching measures to expand the science base of the NSI, including increased public investment in scientific research. The DST will specifically target the expansion of selected strategic, emerging and underdeveloped STI areas in order to improve economic competitiveness through long-term and cross-cutting research, with a specific focus on postgraduate research. As discussed above, the DST will work with line departments and business to develop sector STI plans, which will form the basis for the expansion of research*

and knowledge creation in priority sectors and relatively mature domains where such activities will lead to increased competitiveness. The DST will further coordinate support for foundational aspects of the NSI, such as human capital development and infrastructure provision related to these STI priority areas.

Chapter 4: An enabling innovation environment in South Africa

EQ 4.1 (4.2 Policy intent: Brand South Africa as an innovative country):

The establishment of an agency to coordinate system-wide science engagement will be guided by the DST's science engagement strategy. Such an agency will play a critical role in shaping perceptions among South Africans by profiling South African science and science achievements, and demonstrating their contribution to national development and global science, thereby enhancing its public standing.

EQ 4.2 (4.3 Policy intent: Adopt a broader conceptualisation of innovation beyond R&D):

The White Paper adopts a broader conceptualisation of innovation and its sources. Recognition that the sources and nature of innovation go beyond R&D-led and radical innovation, and include imitative, frugal and incremental innovation, is critical for a developmental state and emerging economy. Design and engineering activities, on-the-shop-floor attempts to improve productivity, and investment in organisational learning, learning by doing, using and interacting, and observing what others are doing are important activities that drive innovation. Appropriate access mechanisms to the formal intellectual property rights (IPR) registration system, will be introduced to ensure that all innovations, regardless of source and nature, may find protection, where relevant and desirable.

The concept of open innovation will be supported, acknowledging that open innovation and protection of IP assets are not mutually exclusive, but can complement each other in strengthening the NSI. In developing countries, indigenous knowledge and know-how are particularly relevant. The DST will continue with initiatives to strengthen the recording, protection and utilisation of this knowledge, to the benefit of the knowledge holders and the country. Previously, focus resided on the supply-side of innovation with less of a market-driven approach. This White Paper has a strong focus on addressing the needs of the business sector and thus has an increasing demand side focus, all the while noting that innovation may result from a combination of both demand- and supply-side driven activities. Innovation for inclusive development and frugal innovation are essential to meet societal needs at grassroots level. The DST will continue to champion innovation for inclusive development, especially in the context of developing and empowering both urban and rural communities.

EQ 4.3 (4.4 Policy intent: Adopt a whole-of-society approach to innovation):

In addition to the general innovation compact and the policy nexuses around critical policy areas, there is a need to strengthen the role of STI policy in enhancing the competitiveness of firms, sustaining high growth in the productive and services sectors, and supporting the development of new firms and industries. The NSI currently contributes to the Industrial Policy Action Plan (IPAP), but there is room for the DST, science councils and relevant public entities across the NSI to achieve greater impact.

The current contributions of the NSI to IPAP will therefore be deepened to ensure that the programmes of science councils are aligned with priority industrial sectors, as well as with new growth opportunities identified by, among others, the Industrial Development Corporation (IDC). STI will be integrated into future frameworks and legislation to advance national industrial and economic objectives. An important step towards aligning STI and industrial policy will be the establishment of the proposed policy nexus on trade and investment.

EQ 4.4 (4.5 Policy intent: Use public procurement as a vehicle to further innovation):

Therefore, strategies will be developed to ensure that government is the first customer when it comes to using locally developed technologies. Government's Infrastructure Build Programme is one example where locally developed technologies can be supported and tested. A supportive legislative environment will be ensured, and where the success of new industry development efforts (e.g. in the fields of medical devices, ICT and environmental technologies) depends on government procurement, a formal strategy will be jointly developed by the DST and the government department responsible for procurement.

The role of the Public Finance Management Act, 1999 in R&D-related activities will be made clear (e.g. to differentiate collaboration and partnerships from procurement-related activities). Technology conditionality will be built into large procurement contracts (e.g. fleet procurement for rail) to ensure that South Africa acquires the latest technologies and that there is technology transfer in the localisation process. The Competitive Supplier Development Programme, championed by SOEs, will also be expanded to include local technologies.

EQ 4.5 (Policy intent 4.6.1: Supporting business R&D needs):

Public funding of private sector, needs-based R&D will be increased. A 2014 study by National Treasury on the effectiveness of South African science council partnerships with industry found that there was significant room for improving the focus of research on industry needs. Therefore, government will continue to incentivise partnerships among business, HEIs and Public Research Institutions. The incentive regime will be monitored to ensure the appropriate balance between direct and indirect support to business, with the understanding that both are needed. Furthermore, the mining R&D hub and other instruments to support the private sector will be strengthened.

EQ 4.6 (Policy intent 4.6.2: Targeted technology development and deployment to support firms):

Efforts to localise and diffuse technologies will be intensified through existing and new technology-based support interventions (including the Technology Stations Programme and the Technology Localisation Programme). Sectors with growth potential will be targeted for funding support, e.g. through expanded sector innovation funds.

EQ 4.7 (Policy intent 4.6.4: Specific support for SMEs):

Besides identified challenges such as access to finance and credit, and inadequate infrastructure, SMEs often struggle to innovate, perform R&D, access knowledge and absorb new technology. Therefore, the current model for providing broad-based support to SMEs (e.g. through walk-in support at technology stations) will be scaled up to ensure that even more SMEs can access services, equipment and support in product/technology commercialisation.

SMEs play an important role in the industrial value chain, and initiatives aimed at developing and/or upgrading them as suppliers to government and larger firms will be scaled up. Tailored technological support (e.g. through technology assistance packages) will be intensified to enable SMEs to meet the technical and commercial requirements for becoming qualified suppliers, both locally and globally. Links between SMEs and larger firms will be incentivised to diffuse technology and improve the ability of SMEs to innovate.

A comprehensive support package for SMEs in priority focus areas will be developed collaboratively by the relevant government departments. The existing instruments (e.g. those of the DST, the dti, the Department of Small Business Development, the Economic Development Department and the Department of Public Enterprises) will be aligned to support SMEs and emerging industries.

As an example, both technological and other innovation support to SMEs will be provided to develop new markets or to support systems innovation. New support instruments (e.g. an R&D voucher scheme for eligible firms to cash in with registered

R&D service providers) will be introduced. The maturation and growth of technology-intensive SMEs (e.g. university spin-out companies, or niche SMEs in hi-tech sectors) should be facilitated through the establishment of more innovation hubs providing standard support and coaching/mentoring services, focused on market and enterprise development, including intellectual property strategy development and access strategies to markets. In addition, consideration will be given to regulatory hurdles, as well as burdensome administration and legal requirements.

In pursuit of an inclusive innovation system, particular attention will be given to supporting SMEs in informal settlements, rural areas and cooperatives. Furthermore, to support the transformation of the demographic ownership profile of technology-based firms (and in particular SMEs) in South Africa, DST will develop guidelines, in cooperation with relevant NSI partners, to use intellectual property from publicly funded R&D under appropriate conditions to support women and black entrepreneurs when such intellectual property is commercialised.

EQ 4.8 (Policy intent 4.6.5: Revitalising the role of SOEs in innovation):

State-owned enterprises are important actors in the South African economy, given their role in providing infrastructure and services (e.g. energy, water, transport and communications). SOEs serve as clusters of expertise and have important linkages to various parts of the economy – as anchor institutions in their sectors, as channels for international knowledge spill-overs, and as hubs for human capital development. SOEs are users, funders, performers and collaborators in R&D and technological innovation.

Ten such enterprises account for about 99 per cent of all SOE R&D. However, recent data shows a decline in SOE expenditure on R&D (from a peak in 2008/09. To turn this trend around, the following strategies will be adopted: Domestic technological knowledge gaps require the sourcing of knowledge and R&D services from abroad. For such international sourcing arrangements to be beneficial, they should be linked to a particular strategy for technology transfer and/or localisation in cases where domestic capability is inadequate. Along with the "smart buyer" principles, strategic sourcing from abroad should be linked to national imperatives for technology accumulation, so that, in the medium to long term, SOEs in specific technology spaces will buy from local service providers and institutions rather than from foreign firms.

EQ 4.9 (Policy intent 4.7: Support commercialisation of publicly funded intellectual property):

Offices of Technology Transfer in higher education and science councils play an important role in identifying and protecting new technologies, sourcing licensing partners, and establishing firms to market new technologies. Support for Offices of Technology Transfer will be increased through existing instruments, initially to develop capacity, and, over time, on the basis of the quantity and quality of outputs. To support the transformation of higher education, the type of government support to these offices will be differentiated according to the research intensity and technology transfer maturity of the institution in question.

EQ 4.10 (Policy intent 4.9: Increase the spatial footprint of innovation in South Africa):

Local and provincial growth and development strategies will include innovation plans. "Innovation hubs" will be expanded to enhance provincial growth and development strategies, and promote provincial technology competencies.

As part of these, cooperative research centres (involving industry, science councils and HEIs) and local innovation ecosystems will be developed, where appropriate.

Furthermore, a "no wrong door" policy will be adopted across government, particularly at local and provincial government level, which will see innovation-related enquiries routed efficiently to provide the required information or support. This intervention could initially be implemented through an appropriately located hotline or information kiosks.

EQ 4.11 (Policy intent 4.1: Support innovation for social and grassroots innovation):

The approach will involve widening the range of stakeholders and deepening their engagement in deliberative planning. Over the past decade, grassroots innovation, as a particular priority within the broader innovation for inclusive development agenda, has gained prominence in STI initiatives, both globally and in South Africa. Support for grassroots innovation will be a planning priority in all relevant initiatives. It will be funded accordingly, and monitored in all relevant M&E frameworks.

Developers of local economic development plans, as well as provincial growth and development strategies, will be encouraged to include support for grassroots innovation, and innovation scouting in plans. A multi-tiered package will provide support appropriate to the level of development of grassroots innovators. Mentorship will be incentivised through a government-funded voucher system and awards, and complemented by corporate social responsibility programmes. Grassroots innovators will be capacitated and supported by, for example, supplier development programmes.

Government will further leverage the potential of publicly funded IP to support grassroots innovation. South Africa will develop a country-specific, second-tier patent system, offering a cheap, no-examination protection regime for technical inventions that would not usually fulfil the strict patentability criteria. With the introduction of a substantive patent search and examination system at the Companies and Intellectual Property Commission (CIPC), a preferential accelerated patent examination system will be introduced for SMEs, broad-based black economic empowerment firms, previously disadvantaged individuals, and young innovators, depending on criteria such as the involvement of start-up firms.

Finally, as part of its drive to increase funding to the NSI, and to target investments to help address national priorities, government will work with NSI partners to develop an appropriate funding instrument for grassroots innovation. The objective will be to target both neglected and marginalised groups of innovators, including the youth, as well as to support innovations with high social returns that are unlikely to gain traction because of market and other failures.

EQ 4.12 (Policy intent 4.11.2: Greening the economy):

The current economic crisis and climate change considerations present opportunities to transition to a low-carbon economy by accelerating eco-innovation. Policy makers are also increasingly paying attention to the need for radical and systemic policy innovations as a powerful lever in enabling a long-term transition towards a greener economy. Leading firms and entrepreneurs are looking to create and capture value from new business models that benefit not only the economy, but the environment as well. South Africa is signatory to the Paris Agreement and the SDGs.

To meet these goals will not only require government interventions, but also close cooperation with industry. […] The DST will therefore work with the relevant NSI partners to develop an STI approach to greening the economy, as well as to fund the required research and capabilities. In addition, the economic opportunities of greening the economy will be harnessed to provide jobs. It is estimated that green innovation in South Africa can lead to the creation of around 400 000 jobs.

EQ 4.13 (Policy intent 4.13: Strengthen government's role as an enabler for innovation):

To help entrench a culture of innovation in government, the DST will work with the Centre for Public Service Innovation (CPSI) and other relevant national, provincial and local agencies on challenging the risk-averse mind-set of public servants, *using awards to motivate them and celebrating role models. More specifically, the DST will work with the CPSI to increase service delivery through initiatives such as e-government.*

The DST will therefore work with relevant government departments, such as the DHET, the Department of Basic Education and the Department of Social Development, to develop programmes to build an innovation mind-set from early childhood. Successful innovators, mentors and entrepreneurs will be celebrated as role models. Initiatives to achieve this will include advocacy and awareness, awards across society at all levels of government, and exchange and incubation programmes. Particular attention will be paid to equity considerations, ensuring that people who seldom have the opportunities to become innovators – such as the youth, women, people with disabilities and those with low levels of formal education – are coached, mentored and celebrated. These initiatives will be implemented as a partnership between government, the private sector, higher education and civil society.

Appendix 5

Expanded capabilities to support the knowledge enterprise

EQ 5.1 (Policy intent 5.2: Expanding research outputs and transforming the research institutional landscape):

The university funding formula that was introduced in 2003 had a positive effect on research outputs. Incentives of this nature will be investigated to also support research that informs society, for instance research that improves quality of life.

EQ 5.2 (Policy intent 5.3: Transform the profile of the researcher base):

The DST and DHET will emphasise the development of black and women researchers at emerging researcher level (with a specific focus on black women), and mentor them beyond qualification to take up senior management positions in research management and science institutions.

Over the short term, an increase in the number of researchers will be achieved through focused, fast-tracking interventions that will tap into the PhD-qualified, research-inactive "silent majority" of existing permanent academic staff, especially black and women staff.
The DST will continue its support for the DHET's Staffing South Africa's Universities Framework, which aims to change the number and composition of university staff.

EQ 5.3 (Policy intent 5.4.1: Supervisory capacity):

In order to increase the proportion of university staff with PhDs, direct support for attaining a PhD will be prioritised, particularly for staff at universities where the proportion of PhD-qualified staff is below the norm. Twinning programmes with research-intensive universities and international institutions will assist in addressing the shortfall.

Postdoctoral fellows make an invaluable contribution to the research system by mentoring postgraduate students. The number of postdoctoral fellows hosted at universities and science councils has generally increased, but their contribution has not been optimised because their status has not been defined. The DST and DHET will formalise a set of guidelines on how to optimise the contribution of postdoctoral fellows.

To improve demographic representation among established researchers, the DST and DHET will target and retain a significant number of black and women doctoral graduates, particularly South Africans, in the Postdoctoral Fellowship Programme. Foreign postdoctoral fellows will be targeted in strategic priority areas to alleviate supervisory bottlenecks. At the same time, the DST and DHET will establish a programme for South Africans to pursue postdoctoral fellowships abroad, targeting black people and women.

EQ 5.4 (Policy intent 5.4.2: The human resource development pipeline):

Government will put in place specific interventions to enable all children (and, where appropriate, adults) to become digitally literate. Examples could include making greater use of mobile phone technology and existing public infrastructure in rural areas such as post offices, schools or libraries to introduce children to gaming and coding, and to teach adults digital skills. The private sector will be encouraged to partner with the government in these endeavours.

Currently, too few students are supported at a too low a financial level, and public support for postgraduate studies needs to be increased, especially given that the gradual implementation of free higher education might result in increased postgraduate enrolments. Increased public support for postgraduate studies will also require government, industry and international funders to coordinate their efforts. A framework will be developed for cooperation across government, particularly with departments that have SET postgraduate bursary programmes.

In addition to research Masters and PhDs, the NSI and the economy require technical and other skills that support innovation. Government will therefore expand its student support programmes to include the development of technical, engineering, entrepreneurship and innovation-related skills, such as in IP management.

EQ 5.5 (Policy intent 5.5.1: Diversity of post-secondary education):

The availability of high-quality STEM graduates and teachers, especially secondary school Mathematics and Science teachers and early childhood development practitioners, is essential. At technician level, there is an undersupply of engineering technicians and associate professionals. The sector must develop enrolment targets in line with the skills needed for the labour market. This, in turn, requires assurance that TVET staff have the necessary competence and recent relevant experience.

Increased absorption of doctoral graduates into the economy is only possible if the acquired PhD-level skills and training are appropriate to the needs of industry, government and science councils, among others. Government and industry must be co-creators of human resources and must nurture an increased appetite for PhD-level skills.

EQ 5.6 (Policy intent 5.5.2: Education and training for a future of digital jobs):

Successive industrial revolutions have brought about changes in the nature of work, job markets and training activities for the workforce. Many of the roles, skills and job titles of tomorrow are unknown to us today, and universities have an agile role to play in not only equipping students with approaches to learning and relevant content, but also in understanding and mapping the consequences of the 4IR. Every researcher, whether in the natural or engineering sciences, social sciences or humanities, has a role to play in characterising the impact of the 4IR. Government, universities and relevant research councils will undertake surveys as a form of a reflection-in-action activity on how the country is responding to the 4IR.

EQ 5.7 (Policy intent 5.6.1: Open Science and Open Innovation):

The DST is actively examining the transition to open science and open innovation. This will call for appropriate regulatory frameworks and data skills development, as discussed below. Incentives for open science will be fostered through education programmes and career development programmes for researchers. A focus on citizen science will also be introduced. Barriers to open science will be evaluated and where necessary removed, ensuring that legislation and practice support, rather than thwart, the principles of open and collaborative science. Government will therefore review these, taking into account certain aspects of IPR from publicly funded research and accepting that open science, open innovation and IP, and the associated rights, are not mutually exclusive. Government will also review the policies and institutions governing access to research data and research publications.

The DST, in consultation with DTPS and DHET, will produce a national open science (and data) framework consisting of principles and guidelines for the adoption of open science in South Africa. The framework will be used as a vehicle for awareness raising and training on good practice.

South Africa does not have formal protection for databases. Government will identify a license system for depositing data and for the use of open data. What is in the public domain, what is not, or when it becomes available are pressing issues that need to be dealt with. Ensuring that the needs and wants of the data provider are respected, and determining who can use the data, and under what conditions (research use, teaching and commercial use) are also important considerations. In this regard, the free and open access to public-good data, for instance to monitor environmental impact, also needs to be ensured. The Creative Commons license is a good example for starting to draft specific license types for different types of open data.

Contemporary open science and open innovation requires data to be findable, accessible, inter-operable and reusable (FAIR) in the long-term, and these objectives are rapidly becoming expectations of funding agencies and publishers. The current IPR Act will be reconsidered to ensure that it supports the FAIR guiding principles for scientific data management and storage.

National data storage is a further matter that needs to be addressed. The DST will develop a long-term sustainable business model for a South African research data cloud. Institutional data repositories will be encouraged. More support is also needed for the harmonisation of repositories, which can take place through DIRISA.

Digital technologies are making the conduct of science and innovation more collaborative, international and open to citizens. In the next decade, as connectivity becomes ubiquitous, the shift to more distributed, networked and open organisational models will become commonplace. Those who are unable to make the change will be left behind. Therefore, government will prioritise funding for the provision of digital resources to the communities and institutions that need them the most.

EQ 5.8 (Policy intent 5.6.2: Diversity of knowledge fields):

Studies on the state of health of the different knowledge fields in South Africa will be intensified to allow the DST and other funding institutions to deploy research funding strategically and sustainably. However, support to all academic disciplines, that is, the arts (performing arts and visual arts), humanities (such as languages, literature and philosophy), social sciences (including economics, law, psychology and sociology), natural sciences (physics, chemistry and biology) and applied sciences (engineering and technology, medicine, health sciences, agricultural sciences and computer science) must continue and expand. Government policies need to recognise the importance of language, particularly the home language of children, as the carrier of scientific meaning and information.

Many of the challenges facing humans in the near future, particularly in developing countries, will be solved by the engineering sciences (e.g. infrastructure for rapidly growing cities and improved transport and logistics, water and energy infrastructure, and satellites to ensure information security for the state). Given the present shortage of skilled engineers in the country, government will need to increase support for engineering science and research.

EQ 5.9 (Policy intent 5.6.4: Complex societal problems and inter- and transdisciplinary):

The DST and DHET will encourage universities and science councils to intentionally promote transdisciplinary research by reducing institutional barriers to transdisciplinary research and interdisciplinary research teams. They will also develop structures to encourage input and participation from outside ongoing projects in such a way as to bring researchers from several institutions, representing multiple approaches, together in a transdisciplinary research environment. Funding agencies such as the NRF will support transdisciplinary research and create stepping stones for transdisciplinary careers.

EQ 5.10 (Policy intent 5.6.6: Knowledge diffusion):

The contribution of Public Research Institutions and their outputs in supporting government policy and national priorities needs to be enhanced. Research grant schemes to incentivise collaboration between universities and other Public Research Institutions in inter- and transdisciplinary research will be developed.

Government will support increased networking and the diffusion of knowledge by leveraging existing global partnerships and knowledge networks better, introducing specific programmes for the secondment of South African researchers to institutions in other countries, providing increased support for training abroad, and providing enhanced support for conferences and workshops. An appropriate quota of inter-

national research cooperation engagements and resources will be channelled to historically disadvantaged institutions and universities of technology. Similarly, the role of Offices of Technology Transfer needs to be enhanced, creating demand for in-bound technology transfers.

EQ 5.11 (Policy intent 5.7.1: The institutional environment):

A national coordinator of science engagement in South Africa will be entrenched through legislation. A system-wide science engagement coordination model will be instituted, going beyond the DST and its entities, enabling the higher education sector, industry, research councils, science centres and other relevant stakeholders to collaborate in science engagement.

Government will introduce an approach whereby a fixed percentage of the transfers by STI-intensive departments to their entities is to be spent on raising science awareness. Support for existing science centres will be sustained, and support packages will be developed to establish more strategically positioned science centres, including world-class national flagship science centres or museums. This will require private sector co-funding.

EQ 5.12 (Policy intent 5.7.2: Incentives for researchers):

Conditions for research training grants and research development programmes to science councils and public universities (e.g. research chairs and Centres of Excellence) will make it mandatory for recipient individuals and institutions to communicate their research to the public. Initiatives such as digital literacy programmes can only produce the required results if society is science literate. It is therefore necessary to train scientists and researchers in science communication and science engagement skills. These trained researchers and scientists would then help to introduce developmentally appropriate engagement activities and projects for both adults and school learners. Government will aim to have these skills taken up in the curricula of SET students in the higher education sector.

EQ 5.13 (Policy intent 5.7.3: The reach and effectiveness of science engagement activities):

The development of science engagement and communication skills will be prioritised. Such skills development initiatives will target journalists, scientists, students, learners, educators and science interpreters. Indicators to measure the success of system-wide science engagement performance will be adopted to inform an institutionalised survey on public perceptions of science and country comparison studies.

EQ 5.14 (Policy intent 5.8: Upgrade and expand research infrastructure):

Lack of coordination and integration among departments in providing and accessing research infrastructure leads to bottlenecks and the duplication of effort. Government will establish an intergovernmental coordination and steering platform with a clear mandate and scope, strategy and policy guidelines, co-funding, shared procurement agreements, and joint planning principles to address the lack of coordination.

Government will retain the six national research facilities currently managed by the NRF as research infrastructure platforms. However, the implementation of the South African Research Infrastructure Roadmap will require many more. The management model will therefore be changed to facilitate scale-up, sustainability and improvements in the performance and establishment of these facilities. Training and developing of key human resources is critical to ensure the optimal and sustainable use of research infrastructure. Government will therefore introduce a mandatory requirement that infrastructure provision policies include human resource development support (scientific and technical) for infrastructure development and maintenance through internships, curriculum changes in HEIs, and absorption into the workplace.

Not sharing or integrating research infrastructure leads to isolated and duplicated approaches to research infrastructure deployment and use. To address this challenge, *government will develop programmes and interventions that build a continuum of research infrastructure capabilities at institutional, regional and national level (vertical integration). It will also establish distributed national research infrastructure to optimise and share resources, including for the humanities and social sciences.*

There are weak links and partnerships between the private and public sectors on investment in research infrastructure. Open-access research infrastructure support platforms will be established to encourage private sector investment in research infrastructure.

EQ 5.15 (Policy intent 5.9: Expand internationalisation and science diplomacy):

There will be an intensified focus on attracting STI-related investment to the country, and these efforts will be better aligned with government's general efforts to attract foreign investment into South Africa. The intent is to secure at least 15 per cent of South Africa's GERD from international sources, and to grow this ratio over time.

EQ 5.16 (Policy intent 5.9.3: Planning and coordination for international cooperation):

Coordinating mechanisms will be developed to ensure greater strategic focus and efficiency in international STI cooperation, avoiding fragmentation and duplication. These will include intelligence and information sharing, joint priority setting, and encouraging the exploitation of synergies. Indicators and an M&E framework will be developed to better gauge the impact and outcomes of international STI partnerships. This will include systems for enhanced knowledge management of all South Africa's international STI cooperation initiatives (government and business).

Chapter 6: Financing science, technology and innovation

EQ 6.1 (Policy intent 6.2: Increase levels of funding):

Government recommits to the target of increasing the intensity of R&D investment in the economy so that GERD reaches 1.5 per cent of GDP in the next decade, and an aspirational 2 per cent a decade later. However, funding increases are needed for the STI ecosystem, not only for R&D. A number of specific interventions aimed at realising this objective are discussed below. The efforts of all funding partners complement one another in improving the STI performance of the NSI. Therefore, collaboration and co-funding between the business and higher education sectors, as well as business and science councils, will be strengthened to help address the constraints to business R&D. While the bulk of the increase in STI investment should come from the private sector, government has an important role to play – firstly, through creating an investment-enabling environment, and secondly through increasing its own levels of STI investment. Furthermore, as discussed in Section 6.5, systems will be put in place to ensure funding efficiencies. Government supports the integration of STI in national development, and is of the strong view that STI are key drivers of economic and social development. This is especially so when STI policies are well integrated into national development strategies and combined with institutional and organisational changes to help raise productivity, improve firm competitiveness, support faster growth and create jobs.

National STI-intensive government departments will set appropriate targets for STI in their budgets. In particular, line departments will commit a percentage of their budgets for sectoral RDI plans, and will invest in the science councils that report to them accordingly. Provincial and local governments will actively contribute more to STI funding and, over time, will set appropriate targets for investment in STI as part of their growth and development strategies. Examples of investment opportunities are incubation and testing facilities.

New funding models across the innovation value chain will be used. Examples include corporate social investment, crowd funding, and partnerships/collaborations between actors across different sectors and borders. The growing sector of corporate social *investment funds and non-profit organisations presents opportunities to advance grassroots and social innovation, for example, through venture capital funding. Government will introduce instruments such as matching funding and awareness raising to make greater use of these opportunities.*

There is a specific need for increased commercialisation funding. A Sovereign Innovation Fund will be formed to leverage co-investment by the public and private sectors to address gaps in technology commercialisation. The fund will be designed to complement and enhance existing funding instruments, and to provide large-scale funding for the development and maturation of radical innovations and emerging industries. Within the public sector, agencies such as the TIA, the IDC and the Development Bank of Southern Africa, in cooperation with National Treasury, can contribute to this fund.

EQ 6.2 (Policy intent 6.4: Institutionalise a framework for guiding public STI investment):

The DST, working with NACI, will develop a public STI investment framework. NACI's role will be to undertake foresight studies and provide an independent STI M&E function (including regular analysis of public STI spending). The framework will be based on an analysis of STI funding requirements in line with strategic and sovereign priorities, as well as consultation across government through an interdepartmental STI Budget Committee at the level of Director-General, including national and provincial governments with significant STI mandates.

EQ 6.3 (Policy intent 6.5: Improve funding efficiencies):

Although the case for increased funding is clear, it will also be necessary to optimise existing funding through improved coordination (across government, as well as between the public and private sectors), reduce duplication of effort, and improve synergies. Furthermore, to ensure optimum results from investments, the efficiency of public NSI institutions, to which most of this funding is allocated, will need to be enhanced where necessary.

The South African funding regime currently consists of many different institutions with varying mandates and levels of funding, creating a landscape that is difficult for any innovator or institution to navigate. To simplify the application processes and reduce duplication, the functions and funding instruments of the following institutions, among others, will be harmonised: the TIA, NIPMO, relevant sections of the Small Enterprise Development Agency, the Technology and Human Resources for Industry Programme, the Support Programme for Industrial Innovation, elements of the IDC, and parts of the NRF. The intention is to ensure a seamless transition between functions and instruments.

The administrative capabilities of the relevant institutions will improve efficiency through, for example, simplified application processes, uniform application forms, "one-stop shop" approaches (including an information/ application portal) for addressing questions and assisting applicants, standardised approaches to evaluation, and more information sharing, especially among SMEs. In line with recommendations of the Review of Government Business Incentives led by the DPME, a possibility to consolidate the number of incentives currently available, under a few well-functioning lead agencies, will be investigated. Government's information on public support for business R&D and innovation will be improved appropriately, taking cognisance of the need for sharing restrictions.

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
Technology for poverty alleviation	25588	10140	18328	27546	25448	25395			
Innovation for Inclusive Development							40732	43082	43140

Chapter 2

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 no 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 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 the 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 of 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 reviewing 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 3

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

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).[28] According to Cameron and Tapscott (2000: 81)[29] 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):[30] "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),[31] 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.

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.

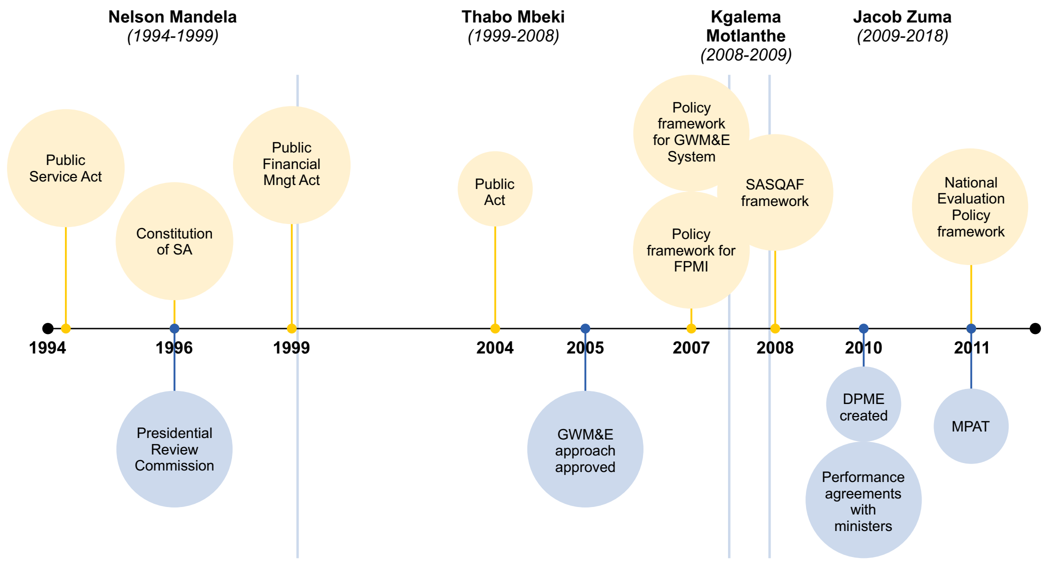
28 *This section is extracted from Charline Mouton's doctoral thesis manuscript (2020) entitled "Performance measurement of policy priorities: Development of a measurement approach to enhance the tracking of government performance".*

29 *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. Cameron R & Tapscott C. 2000. The challenges of state transformation in South Africa. Public Administration and Development, 20(2):81-86.*

30 *Miller K. 2005. Public Sector Reform: Governance in South Africa. England: Ashgate Publishing.*

31 *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: 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
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

Policies and legislation related to performance management	Purpose of policies/legislation
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)[32] 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:[33]

- 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.

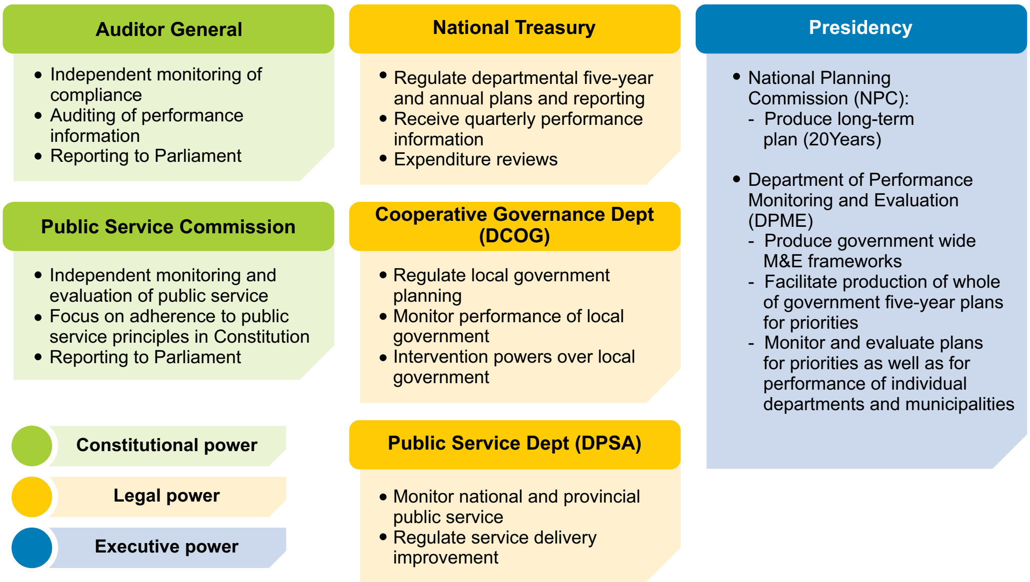
The need to bring about greater coherence between the three agencies in charge of these sub-systems (i.e. The Presidency, National Treasury and the National Statistics Agency) was also highlighted in the 2007 policy document. Figure 14 distinguishes between these

[32] *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.*

[33] *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*

various M&E stakeholders on the basis of their constitutional, legal and executive power.

Figure 14: M&E stakeholders in South Africa[34]



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).[35] 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, 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. It should also be remembered that Annual Performance Plans (which include statements of outputs, targets and indicators) were required as of 2000.

[34] *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.*

[35] *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,[36] 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.

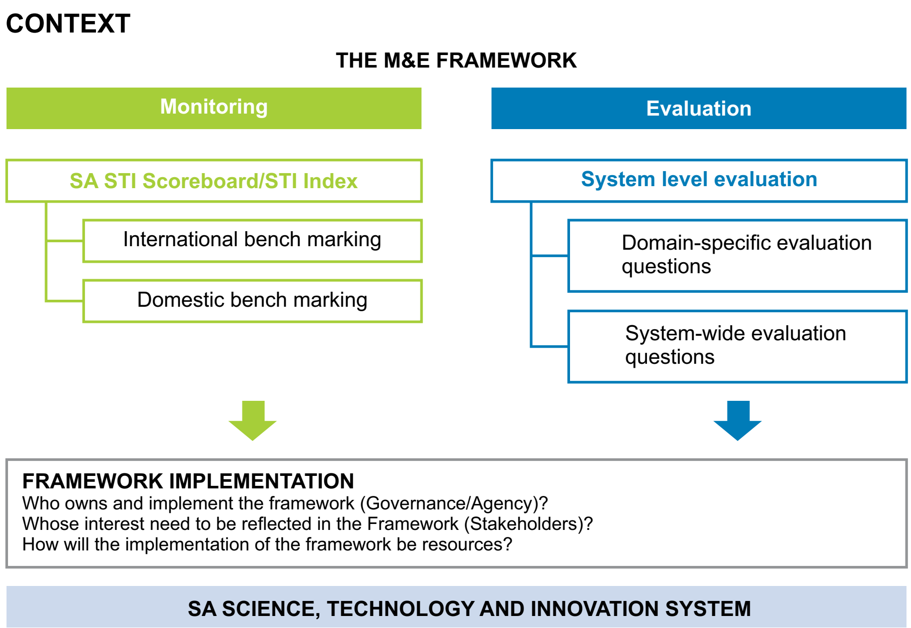
This leads us to the following recommendations.

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



[36] *SciSTIP. 2019. Report on a Monitoring and Evaluation Framework for the South African Science, Technology and Innovation System. Stellenbosch.*

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. 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.[37]

[37] *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 4

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*,[38] 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 postdoctoral 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. 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

[38] *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.*

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)[39] have all invested significant resources and effort into raising awareness among high school learners of the

[39] *South African Agency for Science and Technology Advancement.*

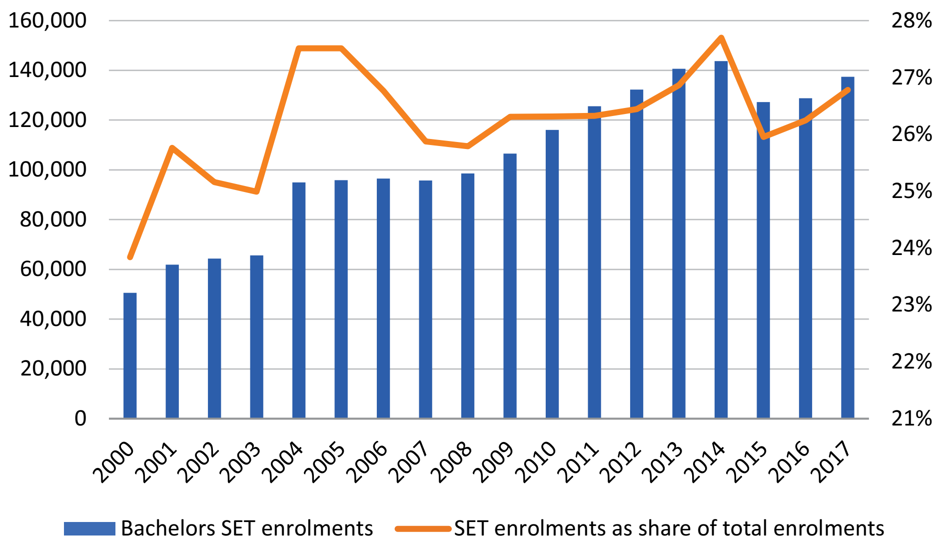
importance and value of science and careers in science. Both the 2006 Youth into Science Strategy and the much later 2016 Science Engagement Strategy include references to a multitude of interventions to achieve this goal. These interventions range from organising science festivals, science weeks and 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.

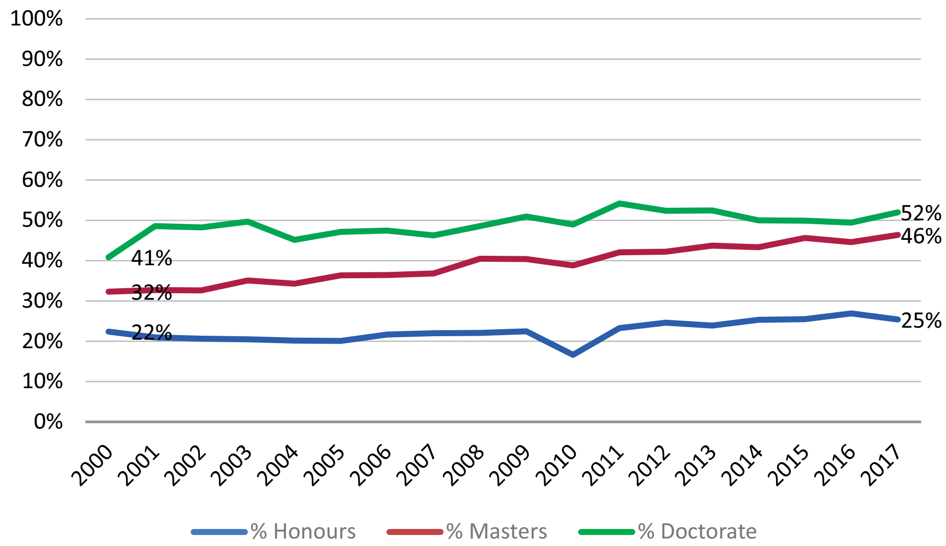
Two other sets of information, as presented in Figure 16 below, give very little hope that this problem will be solved in the near future. The first is the annual enrolments in SET fields at the bachelors level (blue bars); the second is the proportional share that these enrolments constitute of total 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)



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

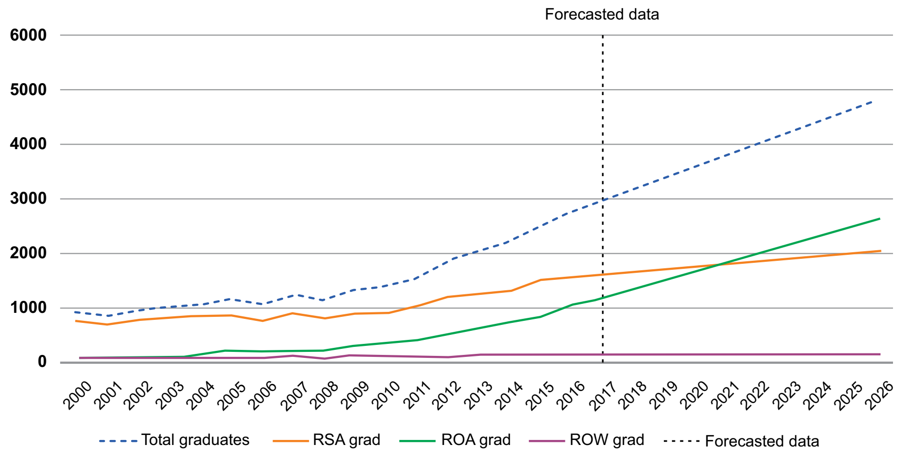
There is only one reference in the NRDS to **attracting foreign talent** (with specific mention of increased numbers of postdoctoral fellows) and it is found within the context of a discussion on internationalisation. There is no reference to an international strategy or programme in either document. 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 the 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[40] 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 postdoctoral 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[41] 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)[42] 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[43]:

> *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.*

[40] *Compound Average Annual Growth Rate.*

[41] *Saxenia A. 1999. Silicon Valley's new immigrant entrepreneurs. UC San Diego Working Papers, No. 15.*

[42] *Saxenian A. 2005. Circulation: Transnational communities and regional upgrading in India and China. Studies in Comparative International Development, Summer 2005, 40(2): 35-61.*

[43] *Saxenian, 2005:p.36*

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[44]:

> *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):

> *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 centre 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[45] 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:

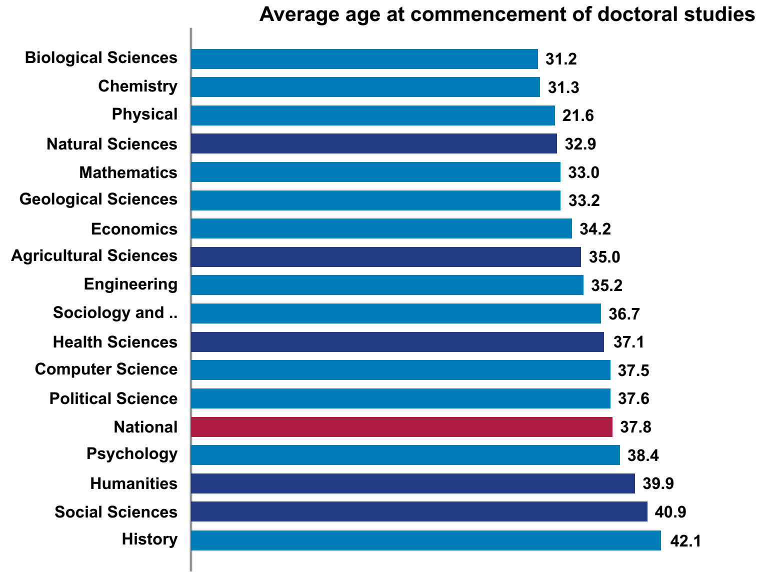
> *The research finds that 55%, or 50 of 91, of the country's $1 billion start-up companies had at least one immigrant founder. This illustrates the increasing importance and contributions of immigrants to the U.S. economy. A 2006 study conducted with the National Venture Capital Association (NVCA) identified 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

[44] *Ibid, p. 36*
[45] *Andersen S. 2018. Immigrants and Billion-Dollar Companies. National Foundation for American Policy.*

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 master's students are concerned, the majority in 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

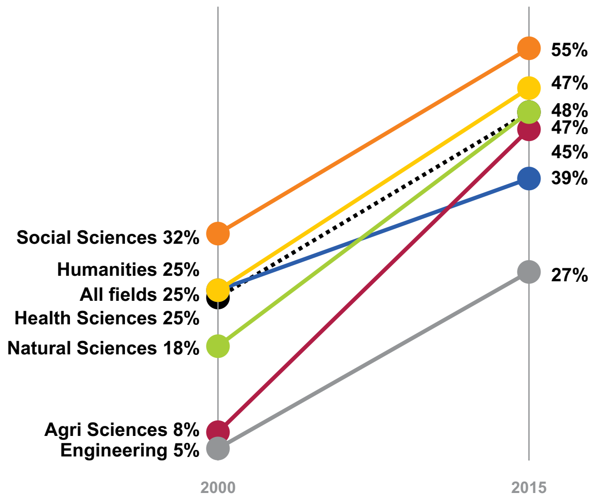
The imperative to **transform the human resource base** for S&T has been a key element of every higher education and S&T policy and strategy since 1994. Various initiatives by the DST, NRF and DHET were launched to address this challenge. These include new funding programmes (such as Thuthuka at the 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,[46] 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.

Figure 20: Change in proportion of black South African doctoral graduates (2000 and 2015)



[46] *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 21: Proportion of female grant holders as a share of all grant holders: 2002 and 2015 compared

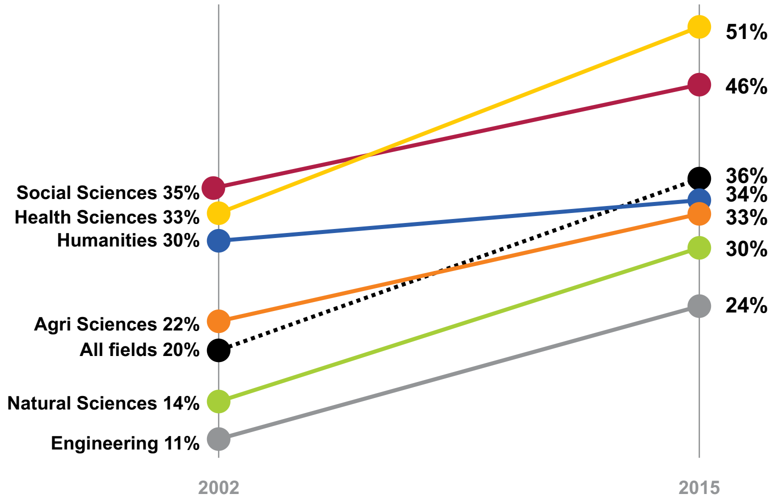


Figure 22: Trends in proportion of (South African) black grant holders: 2002 and 2015 compared

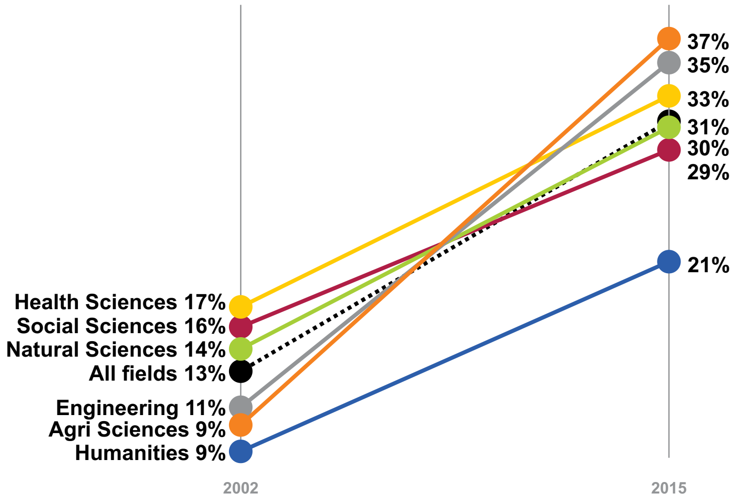
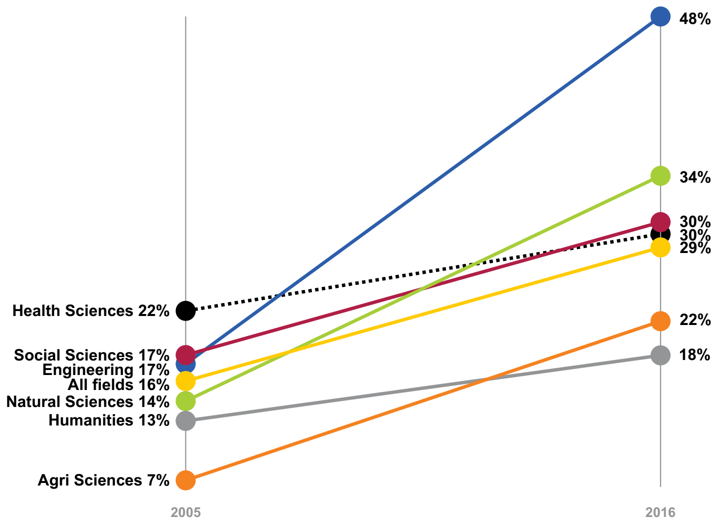


Figure 23: Change in proportion of black authors (2005 and 2016)



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 5

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[47] 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 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*

[47] *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.*

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[48] 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.

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

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[49]

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[50] 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 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*

49 *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.*

50 *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.*

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):

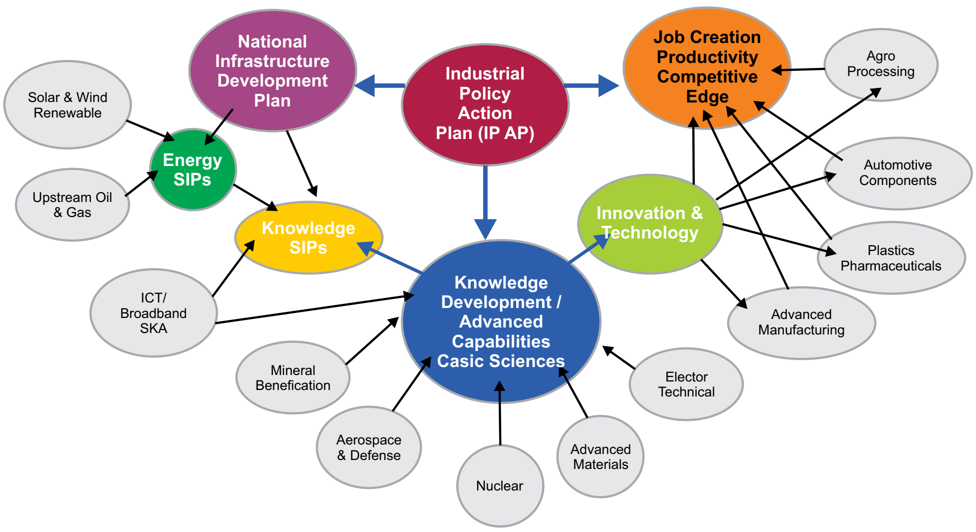
… the related disciplines and the associated science, engineering and technology (SET) fields they underpin are negatively affected. Targeted interventions are required to ensure sustainable development and support of the BS. In this case, the Basic Sciences refer to the scientific disciplines where 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.

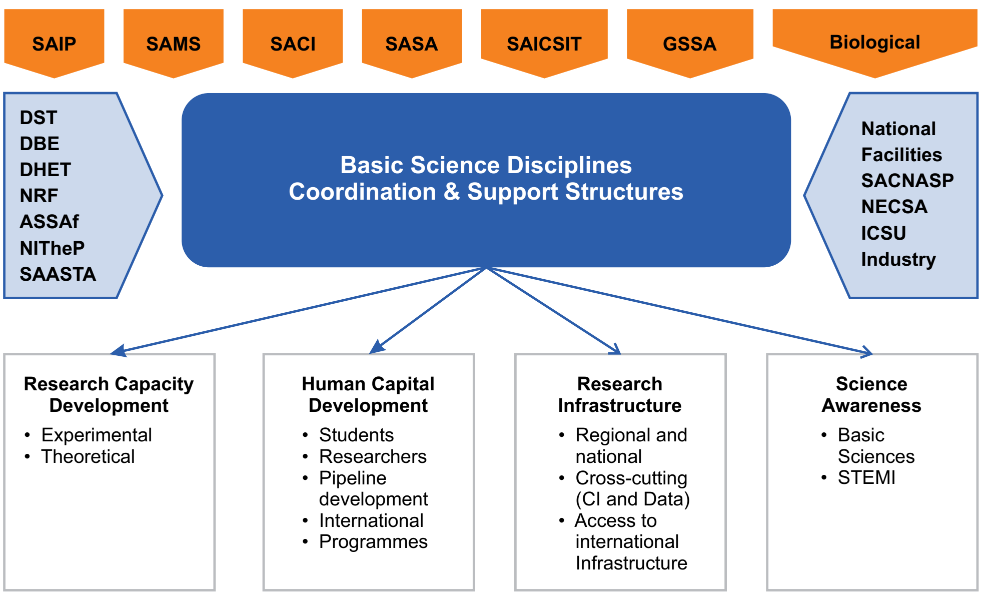
Figure 24: The basic science platform



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.

Chapter 6

From technology strategies to enabling and cross-cutting technology platforms

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)*

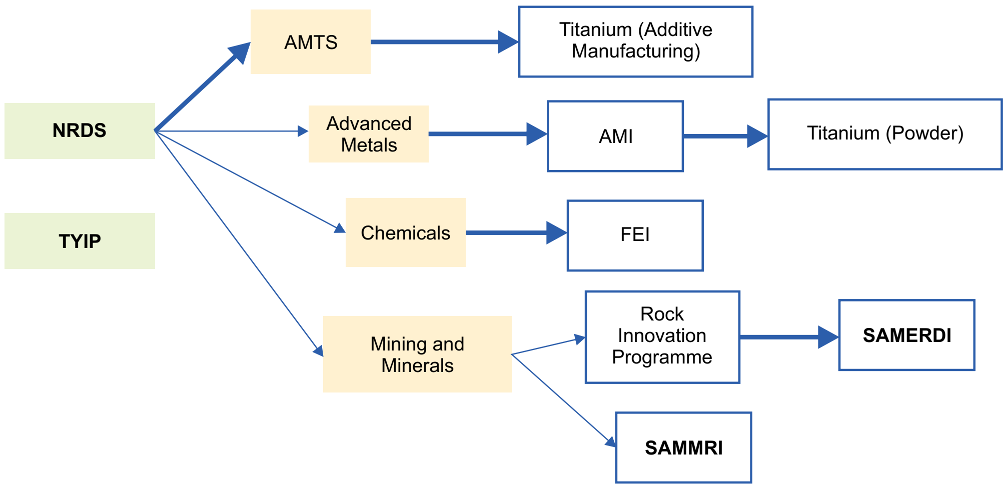
The shift in the narrative from the NRDS to the TYIP does not necessarily signify a shift in emphasis or importance. But it does demonstrate the difference between a more 'technocratic' – even 'linear' – approach to the role of technology in development (NRDS) to an approach where technology serves the 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 an 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.[51] 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.

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.*

[51] *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 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).[52]

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

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**

Source: DST/CSIR (2013: 20)

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.[53] 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.

[52] *DACST. 1999. All our Futures. Pretoria: Department of Arts, Culture, Science and Technology.*

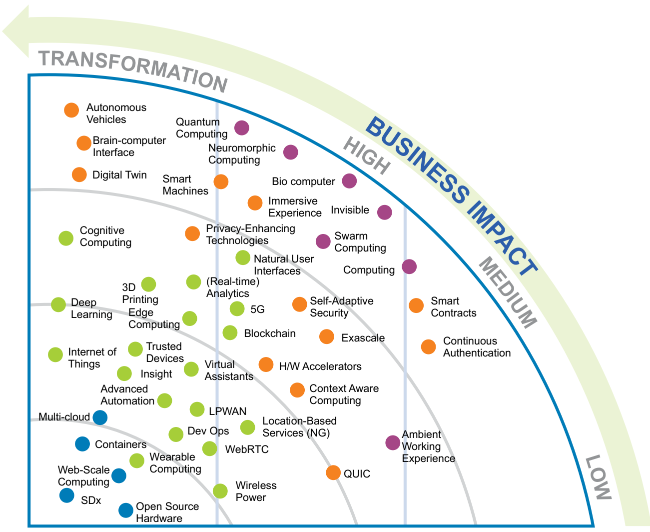
[53] *OECD. 2018. Transformative Technologies and Jobs of the Future. Paris: Organisation for Economic Cooperation and Development. Available at: https://www.oecd.org/innovation/transformative-technologies-and-jobs-of-the-future.pdf.*

In a recent report, Atos[54] 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.

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;

[54] *Atos. 2020. Building the Intelligent Business Platforms of Tomorrow. Available at: https://atos.net/content/mini-sites/look-out-2020/tech-trends/.*

- 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.[55] 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.[56] Maruping[57] 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.

55 *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.*

56 *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.*

57 *P. Maruping, interviewed by Margaret Ward, 26 June 2019.*

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.

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 7

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[58] 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 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',[59] 'mode 2',[60] and the 'triple helix' model.[61] 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),[62] and soon became incorporated in official EU policy discourse through, in particular, the Lund declaration (July 2009). It has since been implemented in

58 *Flink, Tim and Kaldewey, David (2018) The new production of legitimacy: STI policy discourses beyond the contract metaphor. Research Policy 47: 14 – 22.*

60 *Funtowicz S & Ravetz J. 1993. Science for the post-normal age. Futures, 31(7): 735-755.*

61 *Gibbons M. et al. 1994. The New Production of Knowledge: The dynamics of science and research in contemporary societies. California: Sage Publications.*
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.

62 *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.*

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).[63, 64] 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;
- 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.

63 *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.*

64 *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.*

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,[65] 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.

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.[66] 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.

65 *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.*

66 *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.*

'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[67] 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.[68] 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.*[69]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.

67 *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.*

68 *Mazzucato M. 2016. From Market fixing to market-creating: A new framework for innovation policy. Industry and Innovation, 23(2): 140–56.*

69 *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/1032/2815675aa3e4885 22f7277fc 9551e7fc25d6.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[70] 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).

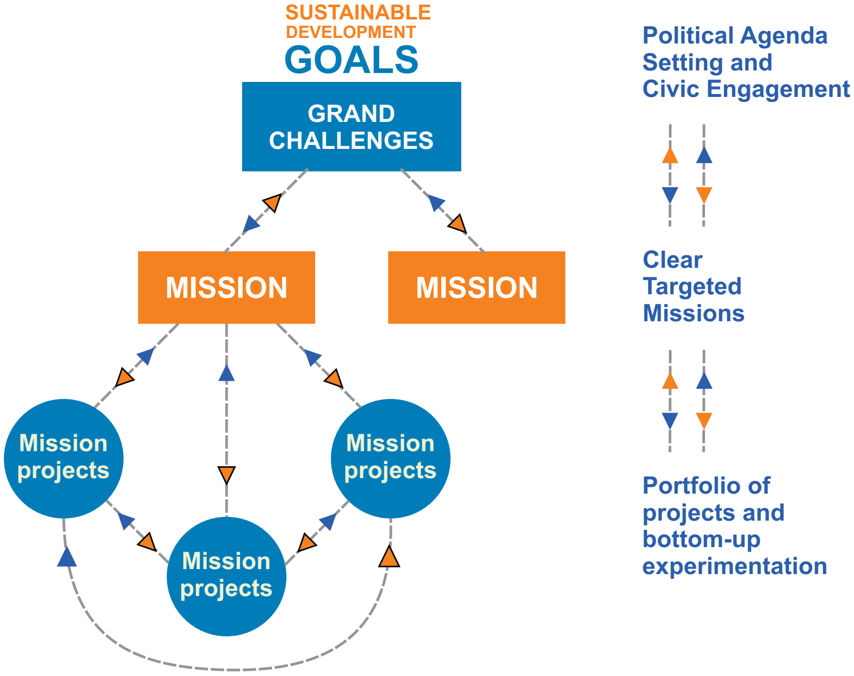
[70] *Mazzucato M. 2018. Mission-oriented innovation policies: challenges and opportunities. Industrial and Corporate Change, 27(5): 803–815.*

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	Diffusion of the results is a central goal and is actively encouraged
The mission is defined in terms of the number or technical achievements, with little regard to their economic feasibility	The mission is defined in terms of economically feasible technical solutions to particular societal problems
The goals and the direction of technological development are defined in advance by a small group of experts	The direction of technical change is influenced by a wide range of actors, including government private firms and consumer groups
Centralized control within a government administration	Decentralized control with a large number of agents involved
Participation is limited to a small group of firms due to the emphasis on a small number of radical technologies	Emphasis on the development of both radical and incremental innovations to permit a large number of firms to participate
Self-contained projects with little need for complementary policies scant attention paid to coherence	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 8

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).[71]

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)
- **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)

[71] *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*

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 postdoctoral 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.

innovation
for a better future

NACI Secretariat | **Tel:** 012 844 0252 | **Email:** naci@dst.gov.za

www.naci.org.za