Gearing for R&D and Innovation in South African State-Owned Enterprises

Findings from Case Studies of SANEDI, ATNS and SAFCOL

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EXECUTIVE SUMMARY

State-owned enterprises (SOEs) are important national assets with a mandate to contribute to sustainable economic growth and South Africa's broad developmental goals. SOEs have the potential to stimulate employment creation and support growth by providing transport, energy, water, ICT and other infrastructure and services.

In March 2019, the Department of Science and Innovation (DSI), published the *White Paper on Science, Technology and Innovation*. This recognised the importance of SOEs in the South African economy and the need to revitalise them to play a meaningful role in South Africa's science, technology, innovation and economic development. As key institutions for human capital development and international and national knowledge sharing, the White Paper also aimed to position SOEs as innovation-driven for the knowledge economy.

The policy challenge, therefore, is how can SOEs in South Africa harness R&D and innovation to meet their mandates? Do SOEs have the necessary innovation and R&D capabilities to respond effectively to current opportunities and challenges? How can government influence SOEs to direct their R&D and innovation activities to support national goals? These strategic policy questions motivated the research that makes up this report. The specific research question underpinning the study was: to what extent and how are South African state-owned enterprises geared to perform R&D and innovation?

Based on insights from stakeholder consultations and an analysis of the academic literature, five dimensions *within organisations* were identified to guide this analysis: human capabilities; technological capabilities; networks; research infrastructure; and governance. These are the inputs needed for effective R&D and innovation by SOEs. The outputs revealed through the research included technological development and adaptation, training services, and networks and communities of practice. In two cases, the strategic outcome of R&D and innovation activities included the establishment of new markets. The study did not systematically survey intellectual property outputs but recommends that future work include a quantitative analysis of outputs and outcomes generated from SOE R&D and innovation.

The study uses the term 'gearing' to assess the extent to which SOEs are prepared, ready and capacitated, through R&D and innovation, to achieve their objectives. The hypothesis being that if an SOE is gearing—or better, appropriately geared—then it is positioned to leverage R&D and innovation to maximise productivity and meet its mandated role within a sectoral system of innovation.

The three SOE cases: ATNS, SAFCOL and SANEDI were selected as examples of SOEs from different economic sectors which demonstrate innovation activity, whether through R&D or other activity. The SOEs were assessed on the basis of the five dimensions discussed. Each was 'excellent' in only one dimension—for ATNS, institutional governance, and for SANEDI and SAFCOL, their networks. Each SOE was rated 'good' in two dimensions: for ATNS, human capital and networks, for SANEDI and SAFCOL, technological capabilities and institutional governance. Likewise, a 'work in progress' assessment applied to two dimensions in each SOE studied, with a common concern about research infrastructure: for ATNS, in technological capabilities and research infrastructure; for SANEDI and SAFCOL in human capital and research infrastructure.

The research concluded that while the SOEs studied incorporated R&D and innovation activities within their strategic outlooks, and had clear examples of innovative performance, there were dimensions in which each could be more appropriately geared—capacitated, resourced and organised—to improve the contribution of R&D and innovation to their efficiency and effectiveness.

Based on the analytical dimensions of firm performance in sectoral innovation systems, together with insights from the comparative analysis of the cases, it was possible to extract a set of potential indicators for each of the five dimensions.

Within **human capability** development, the level of technical and scientific skill and the proportion of technicians supporting researchers and engineers is important. Several measures are available, based on data collected in the national R&D surveys, such as the human resources dedicated to R&D, the type of human resources available—researchers, engineers and technicians—and their qualifications. By extension, measures could be extracted for innovation activities other than R&D. The case studies also suggested other potential measures, such as a count of the establishment and maintenance of training institutions to meet sector-dependent qualification needs. Two indicators are proposed: growth in human resources dedicated to R&D and innovation, and the relative proportion of technicians supporting researchers and engineers.

It is important to measure **technological capability**, because this lays the basis for innovation in the future. The technological capability of an SOE is usually easily identified and their specific technological histories are a source of potential competitiveness. Further, embracing other sources of technological ability within the national system of innovation from public research institutes or universities may improve the overall functioning of the system. The proposed indicator would measure growth in investment in technology, in real terms.

Expenditure on the maintenance and renewal of research infrastructure is necessary for current and future knowledge generation, hence critical to measure. The case study analysis suggests this is a key area to strengthen the functioning of SOEs. Potential indicators, partially sourced from the national R&D surveys, include expenditure on the acquisition of new equipment, land, etc. and the cost of maintaining such infrastructure. Other data is potentially available from the national research infrastructure audit process. New data that may be collected is a list of cooperative agreements around shared infrastructure. The specific indicator proposed is calculating the proportion of expenditure on equipment, land and buildings for research as a percentage of R&D expenditure.

Mapping the sectoral systems of innovation and the case study analysis highlighted the significance for R&D and innovation of well-established local and international **linkages, collaboration and networks** with expert partners. The number and quality of interactions generally strengthens the sectoral—and national—systems. The SOEs studied showed well-established local and international linkages with expert partners within their sector of activity. Here there is little well-established data to draw on. It may be necessary for SOEs to record their linkages with national, regional and global partners, including where there are formal cooperative agreements. It may be useful to distinguish the types of cooperative interactions, whether around training, research infrastructure, research or innovation. As a single indicator, it is proposed that SOEs record annual growth in the number of cooperation partners.

In terms of **governance**, it is critical to assess the integration of R&D and innovation in the enterprise strategy. The case studies illustrate the importance of assessing whether the SOE has an R&D/innovation/technology transfer strategy, whether these are included in the performance compact and whether there are dedicated internal structures to support and promote R&D and innovation.

A key limitation of the study is that results are not generalisable for all SOEs in South Africa, given the small sample size. SOEs are important for an efficient economy and they provide and maintain critical services that citizens rely on for their livelihoods and well-being. Over the last decade, the functioning of SOEs has declined markedly in South Africa. At the same time, many key SOEs show the capacity for future innovation. Government aims to incentivise and support this capacity and the evidence suggests that good governance and active oversight to incentivise R&D and innovation are critical forms of SOE support.

ABBREVIATIONS

4IR	Fourth Industrial Revolution
ATNS	Air Traffic and Navigation Services
AUDA-NEPAD	African Union Development Agency
CeSTII	Centre for Science, Technology and Innovation Indicators
CSIR	Council for Scientific and Industrial Research
DTI	Department of Trade and Industry
DPE	Department of Public Enterprises
DSI	Department of Science and Innovation
DST	Department of Science and Technology
EC	European Community
Eskom	Electricity Supply Commission
GERD	Gross Domestic Expenditure on Research and Development
HSRC	Human Sciences Research Council
ICT	Information and Communication Technologies
Iscor	Iron and Steel Corporation (South Africa)
IP	Intellectual property
IMF	International Monetary Fund
KPI	Key performance indicator
NAC	National Aeronautical Centre
NACI	National Advisory Council on Innovation
NRF	National Research Foundation
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
PFMA	Public Finance Management Act
Prasa	Passenger Rail Agency of South Africa
PRC	Presidential Review Committee
UN	United Nations
R&D	Research and Experimental Development
SAFCOL	South African Forestry Company
SKA	Square Kilometre Array
SOC	State-owned company
SOE	State-owned enterprise
Stats SA	Statistics South Africa
TIA	Technology Innovation Agency

DEFINITIONS AND DESCRIPTIONS

Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.

Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.

Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

Gross expenditure on research and development (GERD) covers all expenditures for R&D performed on national territory in a given year. It thus includes domestically performed R&D which is financed from abroad but excludes R&D funds paid abroad, notably to international agencies.

Innovation is defined according to the OECD's Oslo Manual (OECD, 2018) as a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products and processes and that has been made available to potential users (product) or brought into use by the unit (process).

Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture and society—and to devise new applications of available knowledge.

R&D personnel refers to all persons employed directly on R&D, as well as those providing direct services such as R&D managers, administrators, and clerical staff.

Researchers are R&D personnel engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned.

State-owned enterprises (SOEs) are public corporations owned by government units mainly engaged in market production and sale of the kind of goods and services often produced by private enterprises. These consist of resident non-financial corporations and quasi-corporations that are subject to control by government units, control over a corporation being defined as the ability to determine general corporate policy by choosing appropriate directors, if necessary. The government may secure control over a corporation:

- by owning more than half the voting shares or otherwise controlling more than half the shareholders' voting power; or
- as a result of special legislation, decree or regulation which empowers the government to determine corporate policy or to appoint the directors.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF BOXES

INTRODUCTION

Innovative SOEs for economic growth and inclusive development

Globally, state-owned enterprises (SOEs) perform a critical function within the economy and society (OECD, 2018b). They represent public investment that creates the conditions for business and citizens to flourish, by providing essential infrastructure for energy, transport, water and agriculture. Without the services provided by large SOEs in South Africa such as Eskom, Transnet, Prasa and Telkom, businesses and individual citizens would bear considerable costs for essential services; the country would be less attractive to foreign investment and citizens would have less access to the public goods that are essential to well-being.

How SOEs can best help transform economic trajectories has been a topic of robust discussion globally for the past two decades. The success of China, where the governing party used its control and influence over SOEs to promote economic development to meet national policy goals is particularly relevant (OECD, 2016). In a country like South Africa, with significant inequalities and development challenges, government aims to deploy SOEs to help realise strategic economic growth and human development imperatives, seeing SOEs as "critical in attaining the objectives of the Developmental State" (The Presidency, 2013).

Today, SOEs operate in a world of rapidly changing digital technologies, including artificial intelligence, which can be applied to business and socio-economic development, bringing potentially significant advances. In South Africa, SOEs have historically played a key role in the national system of innovation, conducting R&D and developing new technologies, often in partnership with the higher education sector and public research institutes, and offering technical training and skills development (see for example (CeSTII, 2019, pp. 33-44). To remain efficient and competitive, SOEs must adopt a strategic stance to build and use their capabilities for R&D and innovation (Mustapha, Kruss, & Ralphs, 2018).

The policy challenge then, is how can SOEs that the South African government controls be harnessed to achieve national goals? Do SOEs have the necessary innovation and research and development capabilities to respond effectively to current opportunities and challenges? How can government incentivise SOEs to orient their R&D and innovation activities to meet developmental goals? These strategic policy questions motivated the research that is the focus of this report. The specific research question that was developed for the study was:

To what extent and how are South African state-owned enterprises geared—in terms of their human and technological capabilities, networks, research infrastructure and governance—to perform R&D and innovation?

Institutional challenges: corruption and poor governance

One of the analytical dimensions that we have identified for an understanding of R&D and innovation is governance (of R&D and innovation). It is not possible to position this issue without a broader discussion of the national governance of SOEs as a framework element. This context is characterised by the widespread scale and reach of 'state capture', defined as the illicit exploitation of public funds for private gain (Bhorat, et al., 2017) (Chipkin, et al., 2018) (Marchant, Mosiana, Holden, & Van Vuuren, 2020). There is evidence that the procurement spend of the SOEs responsible for energy supply (Eskom) (Eberhard & Godinho, 2017) and passenger transport (Prasa) (Public Protector South Africa, 2016b), for example, have been captured by extractive patronage networks, which negatively impact the infrastructures essential to routine business operations and the daily quality of life for citizens. South Africa is only beginning to deal with the opportunity cost of diverted resources, in a period of tight fiscal constraints, ratings agency downgrades and economic slowdown.

As a result, sections of the media and civil society organisations increasingly view some SOEs as "a drain on the fiscus", and entities the country may do better without. There have been periodic calls to privatise some SOEs, both in the traditional print media and social media, and from business and civil society lobby groups (Robb & Mondliwa, 2018). There is precedent for this historically: the steel manufacturer, Iscor, was partially privatised before 1994, and completely privatised post-1994 (Ncopo, 2018). Similarly, the petrochemical company, Sasol, was privatised post-1994 and the telecommunication company, Telkom, was partially privatised in the democratic period (Ncopo, 2018).

Government's policy response has been to reiterate the critical importance of publicly-funded SOEs for a developmental state, and find ways to address the challenges that are currently experienced (see **Box 1**). Important insights into the nature of the problems and potential areas for intervention emerged from the Presidential Review Committee on State-Owned Entities (The Presidency, 2013), which found that significant institutional conditions and practices in and around SOEs were inadequate or missing:

1. The legislative framework
2. Governance, ownership policy, and oversight systems
3. Balancing the trade-offs between commercial and non-commercial objectives
4. Collaboration and coordination between SOEs, and oversight thereof
5. Robust leadership and initiative on crucial transformation imperatives

Box 1: Challenges facing South Africa's SOEs in 2018

In the 2018 State of the Nation Address, **President Cyril Ramaphosa** made a number of decisive statements concerning government policy on SOEs:

"Government will take further measures to ensure that all state-owned companies fulfil their economic and developmental mandates."

"Tough decisions have to be made to close our fiscal gap, stabilise our debt and restore our state-owned enterprises to health."

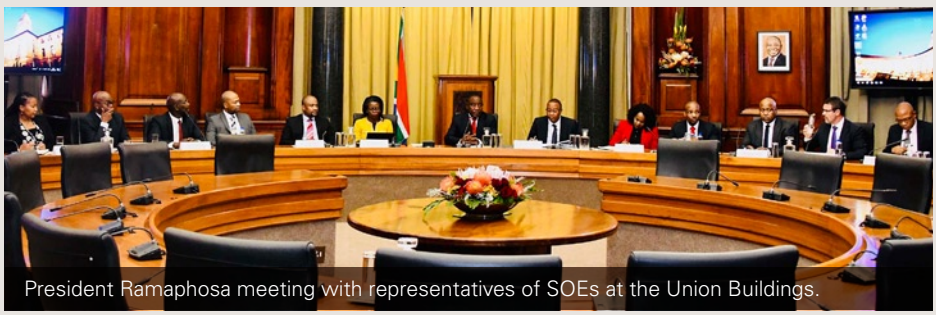
"We will need to confront the reality that the challenges at some of our SOEs are structural—that they do not have a sufficient revenue stream to fund their operational costs. These SOEs cannot borrow their way out of their financial difficulties, and we will therefore undertake a process of consultation with all stakeholders to review the funding model of SOEs and other measures."

"We will change the way that boards are appointed so that only people with expertise, experience and integrity serve in these vital positions."

"We will remove board members from any role in procurement and work with the Auditor-General to strengthen external audit processes."

"As we address challenges in specific companies, work will continue on the broad architecture of the state-owned enterprises sector to achieve better coordination, oversight and sustainability."

Source: Parliament (2018)[1]



President Ramaphosa meeting with representatives of SOEs at the Union Buildings.

1 https://www.parliament.gov.za/state-nation-address-cyril-ramaphosa-president

The problem of widespread corruption in SOEs is not unique to South Africa. The OECD has focused on SOE governance and governance reform over the past decade,[2] investigating corruption and internal controls in SOEs across the world, to determine how better governance practices may be instituted by states. A recent OECD stocktaking report, which covered SOEs in 34 countries, set out the problem:

> In recent years, we have seen how corruption involving SOEs can cause serious economic and political damage and lead to a breakdown of public trust extending well beyond the SOEs themselves. This is why we need a concerted effort to stamp out corrupt and otherwise irregular practices in SOEs, as well as in government institutions exercising state-ownership rights (OECD, 2018b, p. 3)

To address this OECD researchers identified ways that policy makers can "act to maximise SOE productivity by raising their integrity" (OECD, 2018b, p. 11).

In weak institutional environments, there is bound to be a negative impact on the R&D and innovation activities of SOEs. Indeed, there is evidence that the strategic prioritisation of R&D and innovation to enhance the productivity and effectiveness of SOE operations has declined in South Africa (CeSTII, 2017). Research shows a significant decline in SOE R&D performance since 2008, to the extent that in 2016 SOEs were performing at around half the level of that recorded in 2008. Significantly, some SOEs underspent board-approved R&D budgets, and R&D expenditure as a key performance indicator was not included in some shareholder compacts, nor reported on as required (CeSTII, 2017).

Leveraging R&D and innovation to maximise productivity

To maximise SOE productivity nationally it is therefore critical to focus on how SOEs can leverage R&D and innovation to achieve their mandates efficiently and effectively. If SOEs are not able to do so, investment or organisational changes to facilitate R&D and innovation capabilities in the future should be considered. A critical mechanism for government to drive the desired changes, is the design of a set of R&D and innovation indicators against which SOEs would regularly report to their shareholders and stakeholders.

There is currently very little empirical evidence available on the role and nature of R&D and innovation in South Africa's SOEs. Hence this research which includes in-depth, qualitative case studies of SOEs, selected on a convenience sampling basis, that have some R&D and innovation activity. This contributes to an evidence base to inform policy.

The research analyses how these SOEs are 'gearing up' to be prepared, ready and capacitated to harness R&D and innovation to achieve their strategic goals. The research proposes a set of performance indicators that all SOEs would be expected to incorporate into their shareholder compacts and annual reports. National policymakers and SOE organisational leaders should engage with these indicators to inform future plans for R&D and innovation.

This report provides a comparative analysis of R&D and innovation capability and potential in three SOEs:

- Air Traffic Navigation Services (ATNS),
- South African National Energy Development Institute (SANEDI), and
- South African Forestry Company SOC Limited (SAFCOL).

The design and focus of the empirical case study research was informed by a stakeholder assessment of the R&D and innovation challenges experienced in SOEs, summarised in **Box 2**.

2 This report forms part of a series of OECD reports on SOE governance. Since the early 2000s, the OECD has focused on SOE governance and governance reform. For example: Corporate Governance of State-Owned Enterprises: A Survey of OECD Countries, 2005; State-Owned Enterprise Governance Reform: An Inventory of Recent Change, 2011; Boards of Directors of State-Owned Enterprises: An Overview of National Practices, 2013; OECD Guidelines on Corporate Governance of State-Owned Enterprises, 2015; Broadening the Ownership of State-Owned Enterprises: A Comparison of Governance Practices, 2016; State-Owned Enterprises as Global Competitors: A Challenge or an Opportunity?, 2016.

Box 2: R&D and innovation challenges identified by SOEs in 2017

The Department of Science and Technology and the Department of Public Enterprises convened a consultative stakeholder workshop in August 2017 to identify R&D and innovation challenges experienced by SOEs. Key issues raised were:

- Operational efficiency requires SOEs to perform R&D geared toward improving and maintaining sustainability.
- Other forms of innovation are important: Is there a means of technological learning from acquisition of high-tech machinery and systems? Are there mechanisms for technology exchange between suppliers of technology and recipient SOEs.
- Forms of R&D that SOEs perform may have produced outputs with currently unknown economic benefits—until they are utilised or commercialised. How many SOEs can benefit from an institutionalisation of IP commercialisation?
- Most large South African SOEs leverage off the local R&D base by collaborating with universities and research institutions to support the development of their own infrastructure and technologies and for continuous operational optimisation. How much potential is there for such collaboration?
- How important is innovation and R&D in terms of the shareholder compact agreements, and reporting to line departments?
- Is there underspending on board-approved R&D and innovation budgets?
- How much R&D is being outsourced, to who and why?
- What are the technological training needs of staff, and how is training used to build local capacity?
- What is the race/gender/ age / qualification profile of staff?
- How important is infrastructure (ICT, road, rail) to their operations?
- Is there clear governance separation between technology expenditure and other broader company procurement initiatives?

Source: CeSTII (2017). Workshop report.

This report addresses many of these concerns through an integrated comparative analysis of the three empirical case studies. Section 1 sets out the conceptual framework adopted to guide the case studies. This incorporated a sectoral system of innovation approach, together with a set of organisational dimensions internal to the enterprise that are significant to leveraging R&D and innovative capabilities. Section 2 provides a comparative assessment of the R&D and innovation capabilities of the three SOEs, using this conceptual framework. Based on this Section 3 proposes a set of indicators that can be used by government and SOE boards to monitor R&D and innovation performance, in order to maximise productivity and effectiveness of SOEs.

1 | CONCEPTUAL FRAMEWORK

Defining SOEs

There are several overlapping and sometimes conflicting descriptions of SOEs. For example, National Treasury refers to Major Public Entities in the Public Finance Management Act (PFMA) Schedule 2A (National Treasury, 2016) and Statistics South Africa refers to public corporations in their statistical release on capital expenditure by the public sector (Stats SA, 2017). Anomalies also exist, for example, while the Department of Public Enterprises refers to State-Owned Companies (SOCs) for SOEs under their purview (DPE, 2018), the Council for Scientific and Industrial Research (CSIR) falls under the Science Council classification in the National R&D Survey, but is considered an SOE in terms of National Treasury lists (National Treasury, 2016). The DTI use the terms SOE and SOC interchangeably, and also refers to 'state-owned entities' (dti, 2018). South Africans often refer to SOEs by their old name, as 'parastatals'.

The definition of SOEs adopted for this study aligns with that used nationally by Statistics South Africa, and internationally by the Organisation of Economic Co-operation and Development. In particular, this definition excludes science councils and their constituent organisations as distinct from SOEs.

The OECD institutional classification of R&D performing units separates institutions into business, government and higher education sectors, as well as not-for-profit organisations (OECD, 2015). The business sector consists of all enterprises that produce for the market—that is, they are "market units".

The Frascati Manual recommends alignment with the System of National Accounts (EC, IMF, OECD, UN and the World Bank, 1993), which refers to SOEs as 'public sector corporations'—market units that are controlled by government. The System of National Accounts provides the following definition of public non-financial corporations:

> These consist of resident non-financial corporations and quasi-corporations that are subject to control by government units, control over a corporation being defined as the ability to determine general corporate policy by choosing appropriate directors, if necessary. The government may secure control over a corporation:
>
> - by owning more than half the voting shares or otherwise controlling more than half the shareholders' voting power; or
> - as a result of special legislation, decree or regulation which empowers the government to determine corporate policy or to appoint the directors (EC, IMF, OECD, UN and the World Bank, 1993, p. 116).

South Africa's SOEs therefore form a sub-section of the business sector in this classification scheme.

Definitions of R&D and innovation

The Frascati Manual (OECD, 2015) definition of research and experimental development (R&D) is adopted, as the most widely-used definition internationally by researchers, statisticians and national accountants. R&D comprises "creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture and society—and to devise new applications of available knowledge" (OECD, 2015).

Innovation is defined by the OECD's Oslo Manual (OECD, 2018) as a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products and processes and that has been made available to potential users (product) or brought into use by the unit (process).

It is important to note that in studies of innovation, R&D is considered as one 'innovation activity' among others. Indeed, the largest reported innovation activity in Africa is the acquisition of machinery (African Science, Technology and Innovation Indicators Initiative, 2019), not intra-mural or extra-mural R&D. SOEs have historically performed intra-mural R&D through dedicated R&D services, representing the capacity for potentially highly novel innovations, or even potentially disruptive innovations. Therefore, R&D is central to the analytic framing of the research.

Sectoral systems of innovation

The systemic nature of R&D and innovation represents a conceptual starting point for this research. The investigation of how SOEs can leverage R&D and innovation to achieve their strategic mandates can usefully be framed within a sectoral systems of innovation approach (Malerba, 2005).

Systems are made up of components and their attributes, as well as relationships between components. In an innovation system, the components are either actors or institutions.

Actors are organisations such as firms, universities, venture capitalists and government departments or agencies responsible for innovation policy, trade and industry policy or regulations and standards. Any of these actors may have an international presence, given the global nature of production systems.

Institutions are

> … sets of common habits, norms, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups, and organizations (Edquist & Johnson, 1997, p. 46).

Institutions may be formal (for example, laws) or informal (such as conventions and norms); national or transnational (for example, patent systems); or they may exist at a local level (for example, transactions) or global level (trade or innovation policies). Institutions are also sometimes referred to as framework conditions in innovation theory (OECD, 2009).

A sector may be characterised as a set of activities that share some common knowledge that is unified by some linked product groups, whether for an existing or emerging demand (Malerba, 2005). Three main dimensions frame the analysis in a sectoral system of innovation.

Firstly, sector-specific ***knowledge base and technologies*** determine the boundary of the sectoral innovation system.

Second are the ***actors and the networks*** that connect them. Actors may be individuals (e.g. consumers, scientists, employees) or organisations (e.g. firms in the value chain, or non-firms such as universities, financial organisations, government, technical associations, etc.). Actors interact through processes such as communication, exchange, cooperation, and competition.

Finally, the ***institutions*** in a sectoral innovation system constrain the types and strength of interactions that the actors have with each other, such as labour markets, sector-specific funding institutions and standards bodies, both local and international.

Sectoral systems of innovation and their application to SOEs

Viewed as a dynamic system, a sectoral system of innovation changes as its constituent components evolve, or reconfigure themselves according to the function that they serve in the system.

In this study it was not possible to investigate how the sectoral systems around each SOE evolve over time. Instead the focus was on mapping the sectoral system as a basis to assess the common institutional attributes that support the pursuit of innovation. The identification of dimensions that account for a well-defined sectoral system of innovation, for selected SOEs, will allow their use as a guide to inform and guide practice for other SOEs.

SOEs, like private sector firms, are actors within particular national policy and industrial systems that span a range of boundaries including the commercial, technological, political and geographical (Lundvall, 1985). When it comes to R&D and innovation, SOEs nest within particular knowledge and technical systems that can enable or circumscribe their capacity. **Figure 1** shows an ideal sectoral system of innovation. It consists of actors and the linkages between them, with the boundaries of the system delineated by the specific technological domain in which the SOE operates, and not geographic boundaries.

The SOE, depicted as the black box in the centre, acts in relation to specific market demand (the brown oval on the right) interacting with actors such as customers, competitors, suppliers and other stakeholders. It also draws on and interacts with other knowledge actors (shown on the left) such as universities or technical training institutions. The SOE must respond to the demands of national regulatory forces, such as the shareholder government department, and national policy frameworks. At the same time, it is shaped by and must interact with global value chains, with actors such as international regulatory bodies, and within international framework conditions. The approach indicates that it is important to analyse the knowledge flows across the system, depicted as black lines, as well as other interactive relationships, depicted as green lines. To maximise productivity, an SOE should be situated within a well-functioning sectoral system of innovation, with strong interaction and knowledge flows between actors at the local, national and global levels.

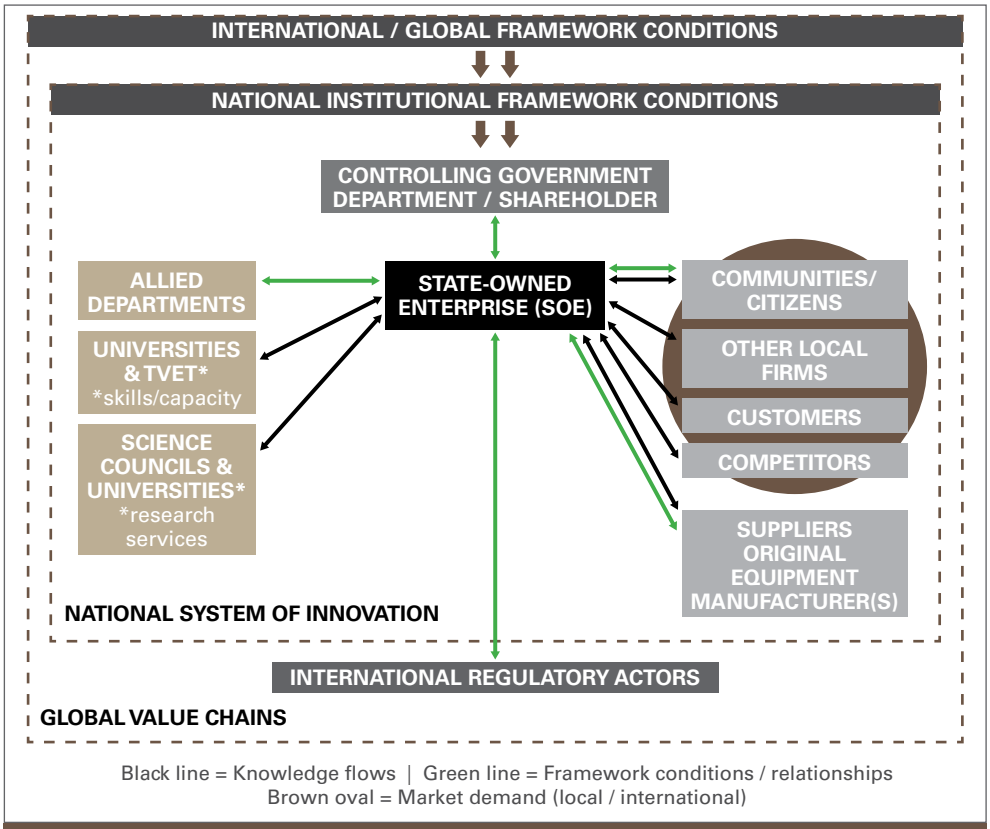


Figure 1: An ideal sectoral innovation system around a state-owned enterprise

R&D and innovation capabilities of the SOE: Five dimensions

To understand how an individual SOE can function effectively within the sectoral system of innovation, it is necessary to open the 'black box' and investigate dynamics within the enterprise itself. Based on the insights developed from stakeholder consultations (see **Box 2**), and an analysis of the academic literature, five dimensions *within the organisation* were identified to guide the analysis: human capabilities, technological capabilities, networks, research infrastructure and governance. How the SOE functions within each of these five dimensions shapes the way the organisation is able to leverage R&D and innovation and, therefore, its ability to deliver goods and services to customers within its resource-based constraints.

Each of these five dimensions are defined here.

Dimension 1: Human capabilities

The ability of people as a whole or as individuals to perform and manage their affairs successfully is how the OECD defines human capabilities (OECD-DAC, 2006). In the specific context of this research, human capabilities refer to the abilities of R&D and innovation personnel within a given state-owned enterprise to generate R&D and innovation outputs and outcomes in line with their organisational mandates.

The presence and appropriate ratio of highly skilled researchers and engineers to technicians is critical. The evidence suggests that the number of both researchers and technicians in South Africa is lower than in high-R&D intensity countries (Mustapha, Kruss, & Ralphs, 2018). In a developing economy such as South Africa there is strong dependence on the acquisition of

new machinery to achieve innovative results. In situations where the level of researchers/ engineers is low, there is a tendency for these highly skilled personnel to engage in the maintenance tasks typically allocated to technicians, instead of direct research or development work. Therefore, it is important to investigate the supply of skilled support staff as well as staff more directly involved in R&D.

Like all firms, SOEs perform different types of R&D, as set out in **Box 3**. To create innovative products or processes, the proportion of experimental development R&D to applied R&D needs to be raised. This in turn requires the necessary research and technical personnel to support such activities.

Box 3: Types of R&D and who does them in South Africa

Data on R&D performed are classified using international standards (OECD, 2015) into three types: basic research, applied research and experimental development.

Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. **Applied research** is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. **Experimental development** is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes (OECD, 2015, p. 29).

The majority (70%) of basic research is performed at universities, whereas the majority of applied research is performed by the business sector (including SOEs) (49%), and higher education institutions and science councils (39%). The business sector performs 60% of the experimental development that takes place in South Africa. SOEs perform mostly applied research (61%) and experimental development (35%) (CeSTII, 2018).

Dimension 2: Technological capabilities

In this study, technological capabilities refers to the entity's ability, based on its accumulated knowledge, to perform R&D and innovation, which results in new technological knowledge development to achieve positive results (Zawislak & Reichert, 2006). Similarly, technological capabilities refer to the ability of a firm to execute a technical function (Guston & Sarewitz, 2014). Following these definitions, technological capabilities within this research includes technologies and knowledge of technologies.

Dimension 3: Research infrastructure

This dimension refers to the resources, equipment and other related facilities and services that are needed to conduct research. It also covers scientific equipment or instruments; knowledge-based resources such as collections, archives or structures for scientific information; enabling information and communication technology-based infrastructure such as computing, software and communication.

The 2016 *South African Research Infrastructure Roadmap* (SARIR) defines research infrastructure as facilities, resources and services used by the scientific community across all disciplines to conduct cutting-edge research for the generation, exchange and preservation of

knowledge (Department of Science and Technology, 2016). According to the SARIR definition, this includes major facilities, equipment or sets of instruments; collaborative networks and knowledge-containing resources such as collections, archives, databanks and biobanks, and research infrastructures may be single-sited, distributed, or virtual. SOEs require access to research infrastructure to conduct cutting-edge research.

Dimension 4: Networks

Networks, as defined in this research, incorporate relationships enacted by and through SOE personnel and institutional processes, and take the form of formal partnership agreements and informal collaborative work undertaken in the conduct of R&D and innovation activities (Hamann & Boulogne, 2008). Partners or collaborators could be private firms, professional bodies, other SOEs, universities, or other actors. Networks have the potential to increase R&D and innovation productivity and performance by transferring skills and expertise through inter-organisational knowledge flows (Kruss, 2006).

Dimension 5: Governance

Governance, in a corporate context as opposed to a political context, refers to the systems, processes, policies and structures available to direct, manage and control an organisation (Camay & Gordon, 2004). Governance also involves the effective and equitable allocation and management of resources for the common good (Camay & Gordon, 2004:17). Using these definitions the research considered how actors within SOEs respond to external governance institutions, focussed specifically on their R&D and innovation activities

The type of interactions and the strength of interactions that a firm has with its partners is shaped by the institutional norms governing the sectoral innovation system (Malerba, 2005). In the case of an SOE, this manifests in the strategic drive and regulatory control it derives from its public sector governing body. Governance is an important tool for building successful, sustainable organisations, and is particularly significant for SOEs as publicly-owned entities. SOEs in South Africa must comply with regulations and laws including the Companies Act of 2008 and the Public Finance Management Act (PFMA) (National Treasury, 2015). A focus on this dimension provides insight into how SOEs are supported through their institutional structures, including funding allocations and other mechanisms that allow new and improved ideas to flow through the organisation. Responsibility for the governance of SOEs lies with the board of directors, management and supervisors.

Given the role that individual SOEs have in the economy, which is to serve a very specific mandate—be it transportation, electricity generation or the development of new sources of energy—the challenge to be more innovative is greater than for private enterprises. There is a greater need for SOEs to perform according to regulation, and rightly so. This makes it harder for SOEs to pursue innovative approaches that require adaptation and new ways of doing business, as these activities may come up against governance constraints. Therefore, the institutional environment is a particularly important factor in analysing the sectoral system of innovation around SOEs.

The concept of gearing

'Gearing' in financial accounting reflects the proportion of debt to equity and is used as an indicator of the extent to which a business is 'sweating' or optimising their balance sheet. From an engineering perspective, it refers to the capacity of the engine and gears, working together, to alter a machine's rate of acceleration.

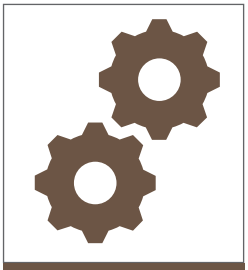


Figure 2: Gearing reflects the capacity of SOEs to utilise R&D and innovation activities to achieve their mandates.

'Gearing' is a useful organising concept for the research and serves to shape an assessment of the extent to which SOEs are prepared, ready and capacitated, through R&D and innovation, to achieve their objectives (**Figure 2**). The hypothesis is that if an SOE is *gearing* or appropriately *geared*, it is positioned to leverage R&D and innovation to maximise its productivity and meet its mandate within a sectoral system of innovation. Comparative analysis of the five dimensions will inform the assessment of how a specific SOE is geared.

An important caveat is that this case study research is not generalisable to the extent that it can provide a normative framework for gearing (which is to say that if a given SOE meets certain pre-defined criteria, then it is geared 'correctly', and vice versa). Rather, it aims to develop a set of qualitative suggestions, based on the comparative analysis of the case study research into the three selected SOEs. Indeed, more case study research could in future contribute empirical evidence to allow for the generalisability of findings, which could further enhance indicator development and evidence-based policy making within this domain.

2 | RESEARCH METHODOLOGY

Research objectives

The objectives of the research, informed by the concepts discussed, are to:

1. Develop a granular understanding of SOEs' R&D and innovation capabilities, including human and technological capabilities, networks, research infrastructure and governance.
2. Contribute to the body of evidence that actors within the national system of innovation can use to understand how SOEs leverage R&D and innovation to achieve their mandated roles.
3. Inform the design of performance indicators to measure R&D and innovation performance and capabilities in South Africa's SOEs.

Research questions

The research methodology adopted for the case studies is an exploratory, qualitative mixed methods approach. The research aims to address one main question:
To what extent and how are South African state-owned enterprises geared—in terms of their human and technological capabilities, networks, research infrastructure and governance—to perform R&D and innovation?

Two sub-questions emphasise that this research question has both a present and future orientation:

- **Sub-question 1**: What are the current human and technological capabilities, networks, research infrastructure and governance of SOEs to perform R&D and innovation?
- **Sub-question 2**: What strategies or plans do SOEs have in place to develop these dimensions?

Selection of SOEs

The Presidential Review Report (Sultan Balbuena, 2014) compiled a consolidated database of SOEs, consisting of about 715 entities as at May 2012, using a broad definition. The database included trusts, Section 21 companies and Chapter Nine institutions. How then were three cases selected for empirical investigation? The selection of cases was based on a combination of opportunity and purposive criteria. Purposive criteria were applied initially, in that the SOE had to be R&D-performing. A pool of possible cases was compiled using opportunity criteria from the R&D-performing SOEs, in that they had participated in the consultation workshop and were prepared to participate in the project as a case study (**Table 1**).

Table 1: Pool of potential cases for selection

Name of the SOEs	Area of operation	Sector
Denel	Manufacture of defence products	Defence
Transnet Rail and Engineering	Freight rail logistics	Rail transport
ATNS	Operation of airports, flying fields and air navigation facilities	Air transport
Eskom	Electricity generation and distribution	Energy
SAFCOL	Forestry business: timber harvesting and processing	Forestry
SANEDI	Direct, monitor and conduct energy research and development	Energy
PetroSA	Exploration and production of oil and natural gas	Petrochemical

The final selection applied purposive criteria, in that the selected cases would need to show evidence of strong performance in their gearing. Hence, the three cases were selected on the grounds that each would potentially provide a rich setting within which to investigate what works, and where challenges lie.

Data collection and preparation

The unit of analysis was the individual SOE within its sectoral system of innovation. For such a case study, a mixed methods approach was adopted using a range of methods and sources.

First, was the analysis of primary documentary sources, notably integrated annual reports, as well as corporate brochures and other grey literature sources, such as presentations and magazine and news articles. Some of these materials were shared with the research team by the respondents, while some were located through keyword web searches. Second, trend data from the National Survey of Research and Development (R&D Survey) was analysed, particularly on R&D expenditure, performance and human resources. Third, to supplement these information sources, the study team visited entities at their head offices or research facilities. Semi-structured interviews were administered with key informants in R&D and innovation units during 2018 (see Appendix A for full interview schedule). **Table 2** summarises the list of interviews conducted for each of the three case studies.

Table 2: List of interviews

SOE	Interview participants*
South African National Energy Institute	1. ITV.SPEC1.CS1, 22 October 2018 2. ITV.SMAN2.CS1, 22 October 2018 3. ITV.SMAN2.CS1, 22 October 2018 4. ITV.AMAN1.CS1, 22 October 2018 5. ITV.EXEC1.CS1, 22 October 2018
Air Traffic and Navigation Services	1. ITV.ENG.CS2, 16 March 2018 2. ITV.ENG.CS2, 23 July 2019 3. ITV.ENG.CS2, 14 February 2019 4. ITV.EXEC1.CS2, 23 October 2018 5. ITV.EXEC2.CS2, 23 October 2018
South African Forestry Company	1. ITV.SPEC1.CS3, 25 October 2018 2. ITV.SM1.CS3, 25 October 2018 3. ITV.SPEC2.CS3, 25 October 2018 4. ITV.SM2.CS3, 25 October 2018 5. ITV.RES1.CS3, 25 October 2018 6. ITV.RES2.CS3, 25 October 2018

*INTERVIEW.ROLE DESCRIPTION.CASE STUDY NUMBER, DATE

A clear set of core questions allowed some flexibility around the sequence and manner in which questions were posed, to take into account the specific nature of each SOE. Respondents were invited to elaborate broadly on question topics, as well as to provide follow up information with the research team telephonically, in person or via email. In terms of data preparation, the interviews were transcribed verbatim from the audio recordings. Transcript data was descriptively coded by grouping and categorising transcribed statements using the study's five dimensions, and to inform the mapping of the sectoral system of innovation (see (Tesch, 1990); also (Saldana, 2016). Due to the limited number of key informant exchanges no specialist coding software was required.

Ethical considerations and dissemination

Informed consent forms were used with key informants before each interview. In line with these commitments, key informants remain anonymous in the written reports and access to the original recordings and transcriptions is restricted. It was expressly agreed at the time of interviews that draft reports would be shared with key informants first to correct inaccuracies, and as part of the validation of the research. Once validated, case study reports could be shared with the relevant government departments, other researchers, and the general public, for further validation and to enhance the dissemination and uptake of research findings.

3 | THREE UNIQUELY INNOVATIVE SOEs? A COMPARATIVE ASSESSMENT OF HOW ATNS, SANEDI AND SAFCOL ARE GEARED FOR R&D AND INNOVATION

ATNS, SAFCOL and SANEDI were selected as three clear examples of SOEs from different economic sectors, which, at a cursory glance, appeared to demonstrate some degree of innovation activity, whether through R&D or other forms of activity. The aim was to analyse, in detail, the innovative performance and capabilities of these SOEs, using the analytical framework described in Section 2, to identify where their strengths and challenges are located. To what extent are these SOEs geared—in one or more dimensions—to develop the innovations they aspire to implement in their organisations or markets?

This section provides a high-level analysis, in several steps, to assess how each SOE leverages R&D and innovation to maximise productivity and play its mandated role within a sectoral system of innovation. The first step compares the mandates and scope of business operations of the three SOEs in **Table 3**. The second step compares the relative performance of their R&D and innovation performance in **Table 4**. The third step is an overview of the SOEs, through a vignette describing the sectoral system of innovation within which each operates. It is important to note that the mapping of the sectoral systems of innovation is illustrative of interactions around R&D and innovation, and not exhaustive of interactions with all actors. The fourth step is a comparative assessment of how geared the three SOEs are. **Table 5** presents the most significant analysis by creating a simple comparative rating scheme using the five dimensions of organisational capabilities.

Table 3: Mandate and business scope of the three SOEs

SOE	Industry	Mandate and business scope
Air Traffic and Navigation Services	Aviation	The mandate of ATNS is to acquire, establish, develop, provide, maintain, manage, control or operate air navigation infrastructures, air traffic services or air navigation services.
South African Forestry Company Limited	Forestry	Formed in 1992, SAFCOL has a dual mandate: a commercial mandate—to conduct forestry business, mainly timber harvesting, processing, and other related activities both nationally and internationally—and a socio-economic development mandate—to deliver an effective return to its shareholder, the Department of Public Enterprises, while contributing to economic development mainly in rural areas. In South Africa SAFCOL currently manages 189 760ha of pine, eucalyptus and wattle forest, including 121 585ha of commercial plantation. In Mozambique it manages 82 547ha of pine and eucalyptus forest, of which 15 258ha is commercial plantation. SAFCOL processes about 10% of South Africa's logs; and SAFCOL's nurseries produce more than ten million seedlings and cuttings annually.

Continues overleaf...

*INTERVIEW.ROLE DESCRIPTION.CASE STUDY NUMBER, DATE

SOE	Industry	Mandate and business scope
South African National Energy Development Institute	Energy	Formed in 2011 as successor to the South African Energy Research Institute (SANERI) and the National Energy Efficiency Agency (NEEA), SANEDI is a Schedule 3A state-owned entity. SANEDI's mandate, as set out in the National Energy Act (Act 34 of 2008), comprises both energy efficiency and energy research and development. This mandate includes optimising the "utilisation of finite energy resources" in South Africa, as well as a large range of R&D and innovation roles, including performer, promoter, adviser, funder, capacity builder and transferor of technology.

Source: Case study reports on SANEDI, ATNS and SAFCOL, CeSTII Working Papers 2b, 2c and 2d, respectively.

Comparison of performance and functioning of the three SOEs

ATNS, SAFCOL and SANEDI were selected as potential examples of innovative SOEs. The case study analysis suggests that in terms of their stated mandate and strategic goals, each appears to function effectively and efficiently. It is important to emphasize here that the SOEs are all very different in their mandates and functioning and, as such, it does not make sense to compare the SOEs on a like-for-like basis, but it is possible to draw out some comparative analysis from the conceptual dimensions articulated in the study. **Table 4** summarises the evidence to support this, reflecting their comparative performance in terms of revenue, business models, international presence and R&D and innovation activities.

Table 4: Characteristics of the three SOEs R&D enterprises

Criteria	ATNS	SANEDI	SAFCOL
Revenue 2018/19 or nearest year	R1,56 billion	R117 million	R1,04 billion
Business and funding model	Almost all of ATNS's revenue (90%) is generated through its regulated business, with its non-regulated business enabling revenue generation (10%) through training and technology consulting services. ATNS's R&D focuses on both aviation and non-aviation related technology with an emphasis on the adoption of the applied business research method, where research activities undertaken	Performer, promoter, and funder of energy efficiency and energy R&D and innovation. Fully funded by a combination of a South African Parliament appropriation (Department of Mineral Resources and Energy) and other national and international sources.	Commercialised timber harvesting, processing, and other related activities. Revenues from the commercial forestry business, including eco-tourism, cross-subsidises socio-economic development programmes.

Continues overleaf...

Criteria	ATNS	SANEDI	SAFCOL
	are with the purpose to innovate, develop, enhance and/or validate technology solutions that have potential to be operationalised or commercialised for primary use in the air traffic management operational environment.		
International presence	Service provision extends to the rest of Africa, including the southern Indian Ocean region. Large portfolio of international regulatory and technological linkages.	International funding forms the bulk of SANEDI's revenue source.	Service provision is in South African and extends to Mozambique.
Types of R&D performed	85% applied research, 7% experimental development, 8% basic research.	90% applied research.	70% applied research, 20% experimental development, 10% basic research.
Other innovation activities	Substantial year-on-year capital investments in training capabilities, networking and collaboration actions, and new machinery and equipment.	Substantial public sector innovation activity augments its R&D outputs, for example in the case of its Smart Grids or Working for Energy programmes, where new technologies are implemented to improve service delivery.	Extensive investment in the acquisition of research equipment and machinery, training, and in local economic development projects. However, capital investment targets not met in 2018/19.
Intellectual property protection	No clear approach to IP protection or commercialisation of IP. Seeks to use IP protection more in future for the adaptive innovations that they create.	Mandated to protect and utilise IP, but no technology transfer function within the organisation.	No clear approach to IP protection or commercialisation of IP. Seeks to use IP protection more in future for the adaptive innovations that they create.

Source: Case study reports on SANEDI, ATNS and SAFCOL. CeSTII Working Papers 2b, 2c and 2d.

ATNS: Fostering a culture of innovation

With headquarters in Johannesburg, Gauteng, ATNS provides services in all nine provinces —to nine ACSA airports and a small number of regional airports. Although ATNS's mandate principally concerns air traffic management within South Africa, as noted, the SOE's scope of service provision is growing beyond the country's borders to the rest of Africa, including the southern Indian Ocean region. The ATNS Integrated Report 2018 provides a clear statement with respect to the company's future growth potential. In this context:

> *Increased air traffic movement on the continent will be the backbone of our long-term financial sustainability as there is little room left in the local market to improve our bottom line.*

Other notable developments within the ATNS national operating context include a relatively new White Paper on Civil Aviation (2017), which aims to bring greater private sector involvement and coherence to the aviation industry in South Africa, including its 135 licensed airports. Globally, changes at the technological frontier of air traffic management, as well as within air traffic management regulatory bodies, suggest far greater interoperability between national and regional systems, to improve safety and combat cybersecurity breaches.

The ATNS sectoral R&D and innovation system mapping in **Figure 3** highlights these and other framework conditions that impact the SOE. The system mapping provides evidence of diverse linkages between ATNS and formal knowledge producers, both locally and abroad, as well as training partners. With the need to adhere to stringent safety requirements, the mapping reflects the highly regulated nature of national and international regulatory authorities, associations and conventions, including the Civil Aviation Authority, International Air Transport Association and the Chicago Convention (which established the International Civil Aviation Organisation of the UN). The presence of large multinationals such as Thales, an important original equipment manufacturer (OEM), and supplier of key infrastructure to ATNS is also a notable feature of this system, as is the absence of competitors, given it's positioning as a South African entity, within an African continental and southern Indian Ocean economy context.

As a key innovation activity, ATNS performs research and experimental development (R&D) which aims to solve air traffic management and navigation-related problems, including the adaptation of overseas-manufactured equipment to local conditions and exigencies. The outcomes of R&D lead to predominantly new process development or process improvements (process innovation), with some new product development and improvement (product innovation). Notably, ATNS operates an extremely well-established training academy, where staff are capacitated for various roles within the ATNS business and suite of regulated services (product and process innovation).

Technologically, ATNS makes use of advanced and high-tech facilities including ground-based primary and secondary radar and navigation and surveillance systems which are procured routinely as part of the entity's capital expenditure programme. Advances in satellite-based systems, and interoperability, will necessitate adjustments to ATNS systems in the future. Senior executives at ATNS interviewed for the research expressed the view that relatively little has been done to leverage the skills and knowledge present in South Africa to produce some of these facilities systems locally. R&D and innovation could lead to the development of new products for the country, but this is not necessarily a 'quick win'.

In terms of research infrastructure, the ATNS R&D team use predominantly desktop applications in relation to existing air traffic management infrastructure and systems, as opposed to dedicated laboratory or experimentation facilities. Significantly, the physical and digital infrastructure that ATNS implements in its core business represents, in effect, a type

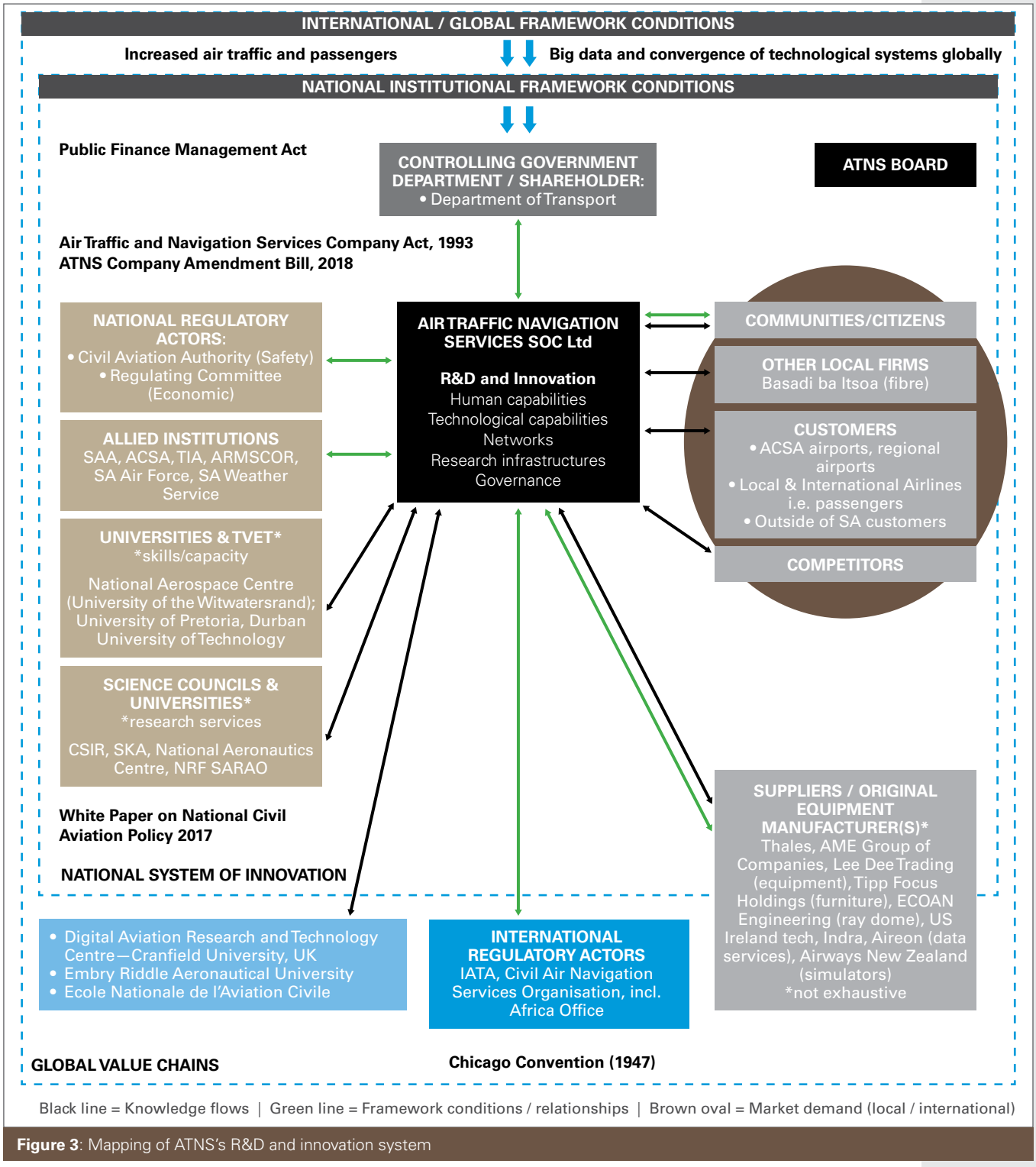


Figure 3: Mapping of ATNS's R&D and innovation system

of research infrastructure that is—and can be used—as the basis for R&D and innovation activity.

ATNS does not pursue R&D or innovation in isolation; it works with a number of partners including South African and international universities, science councils, and other agencies. The National Aeronautical Centre (NAC), the Technology Innovation Agency (TIA), and the Council for Scientific and Industrial Research (CSIR) are among the key South African partners

that help it to fill critical capacity gaps. It also works with private sector actors, such as Aireon, on special projects. To deepen its networks, ATNS organises the annual AviAfrique innovation summit to discuss key issues for air traffic navigation management and service provision. This gathering helps to cement existing relationships, especially with African partners, and build new ones. Collaboration fills a number of purposes: sharing knowledge and ideas; promoting human capital development, in particular development of skills in the ICT field and addressing historical imbalances of high-skilled engineers; remaining abreast of advancements at the technological frontier; as well as working together with local and global industry regulatory actors to ensure air traffic is accident free. An openness and willingness to engage in collaboration with other role players, such as the Square Kilometre Array (SKA), where there is a good business case to do so or a key problem to be solved, was also evident.

At the governance level, ATNS appears to have elevated the role of R&D in the past two years. It has elaborated a strategy for R&D, with the fourth industrial revolution (4IR) as a key framing concept, with a dedicated steering committee. Both executive management and the board support the strategy. In this way, R&D is beginning to play a more prominent role within the business model. In terms of innovation, following a shift in strategic thinking in 2010, ATNS appears to be fostering a culture of innovation internally.

The detailed case study argues that ATNS has succeeded in fostering a 'culture' of R&D and innovation within the organisation, in the context of its unique and favourable position as arguably the leader of air traffic and navigation services on the African continent, and within the southern Indian Ocean more broadly. This culture of R&D and innovation is reinforced at the level of executive leadership and the board, but also reflected in increased expenditure on R&D over the past five years, and in events such as the AviAfrique innovation summit.

SAFCOL: Strong technological capabilities and social compacts with communities

The establishment of SAFCOL in the early 1990s formed part of the then government's strategy to re-build the economy and its institutions, including SOEs. In 2007, Cabinet announced its intention to exit commercial forestry, by selling SAFCOL and its key subsidiary Komatieland Forests. This decision was subsequently reversed in 2009, under then public enterprise minister, Malusi Gigaba. It is in this wider context—of a newly established organisation and then subsequent political uncertainty—that the evolution of R&D and innovation at SAFCOL should be analysed.

The South African forestry industry employs 158 400 people, including 88 200 in the primary sector (growing, harvesting), and 70 200 in processing (sawmilling, mining timber, pulp and paper, and other).[3] According to Klerck, in 2000 the industry employed 100 000 people, with 60 000 in the primary sector and the balance in processing. This suggests employment growth in the industry. Other formative factors within the SAFCOL operating context include the global, regional and local impacts of climate change, increasingly stringent international standards for sustainable forestry and the current economic downturn in South Africa. Substantial sector-specific risks faced by SAFCOL include fire risk, timber theft, pests and disease.

The mapping of the SAFCOL sectoral R&D and innovation system in **Figure 4** highlights these and other framework conditions impacting the entity. Distinctive in this system are the significant human populations of local communities living in areas with forests under SAFCOL's management; the presence of a large number of allied institutions, including and especially industry associations, as well as university collaborators; the presence of the Forestry Stewardship Council (FSC), the key international regulator of SAFCOL activities; the presence of a limited number of multi-national corporations and a number of South African multinational corporations, such as Sappi and Mondi.

3 It is important to note that SAFCOL is not a land owner: land and natural resources under SAFCOL management in its South African operation is owned by the Department of Agriculture, Forestry and Fisheries and the Department of Public Works, of which 57% is subject to land claims.

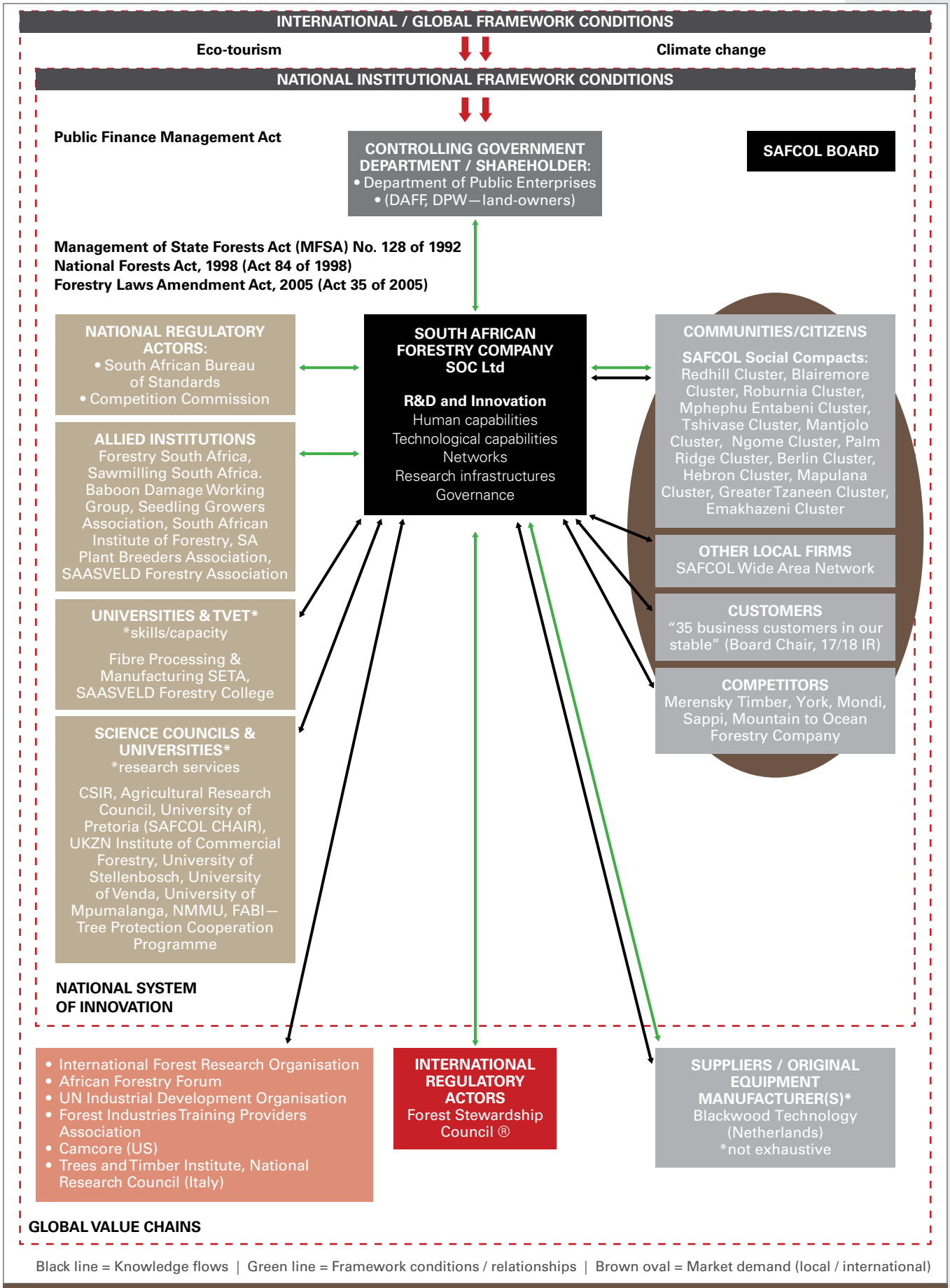


Figure 4: Mapping of SAFCOL's R&D and innovation system

At the level of governance, R&D and innovation is positioned as integral to SAFCOL's core business and is reported in its annual integrated reports, with varying degrees of detail. While R&D collaborations are encouraged, as is strengthening the capabilities of R&D in wood science and technology, it is notable from SAFCOL's 2018/19 Integrated Annual Report that capital investment key performance indicators were not achieved. The appointment of an acting executive for innovation, marketing and strategy signals that SAFCOL prioritises innovation at the highest level. SAFCOL has also 13 social compacts with communities. To the extent that these compacts support productive relationships between SAFCOL and communities, it could be possible to leverage new innovation and innovative potential through expanding activities, including training.

Technologically, SAFCOL's capabilities are twofold: timber capabilities and non-timber capabilities. Timber capabilities span the entire value chain, from genetic engineering and breeding to sawmilling and beneficiation of timber products. Non-timber capabilities encompass community-based forestry, training, and eco-tourism.

Within a workforce of over 2 000, a relatively small combined team of less than ten scientists, technicians and managers deliver wide-ranging research on silviculture practices,[4] pest and disease tolerance, genetic improvements, wood-quality testing, growth and yield modelling and engineered wood products. To redress longstanding national capacity gaps in wood science and technology, SAFCOL builds R&D capacity in partnership with local universities, including through bursary support, and funding of a SARCHI chair at the University of Pretoria. More broadly, SAFCOL's human capabilities to perform innovation extend beyond its R&D team. At the executive level, SAFCOL has appointed, in an acting capacity, an industrial engineer responsible for SAFCOL's marketing, strategy and innovation.

In terms of research infrastructure, SAFCOL has a dedicated R&D centre at Sabie in Mpumalanga province, close to its Tweefontein plantation and nursery. The centre houses a tissue culture laboratory, and is expanding its suite of equipment to include cryogenic freezers.[5] Challenges experienced by the R&D team include procurement delays and on-plantation transportation challenges though, on the whole, the team reported that their infrastructure needs are well supported.

SAFCOL does not pursue R&D and innovation on its own but with a wide range of universities, industries, international and community partners. Collaboration helps SAFCOL to solve different kinds of operational problems, contributes to the capacity development of its researchers, and the organisation more broadly, and helps to grow its relationships with the communities in which it works.

Looking forward, R&D and innovation strategies include evolving plans to develop a techno park at Sabie to drive sector industrialisation; increasing the productive capacity of its Timbadola Sawmill; a multi-faceted training programme; and a host of capacity building R&D partnerships with universities and international organisations

In terms of R&D specifically, SAFCOL has an advanced R&D capability that could be strengthened and enhanced through 'quick wins', such as increased investment in personnel, especially at research assistant level through to greater operational support to the R&D team in infrastructure and equipment procurement. Continued investment in collaboration and networking, including formal R&D partnerships, could enhance SAFCOL's competitiveness over the longer term. In terms of innovation capability more broadly, SAFCOL has a diversified portfolio of non-R&D innovation activities—from co-operatives and training to eco-tourism and cultural and creative industry initiatives, but the innovation element is largely missing.

4 Silviculture is the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis (Adams, et al., 1994).

5 Cryopreservation retains cells or tissue matter at sub-zero temperatures.

Two dimensions are particularly crucial in gearing SAFCOL to perform R&D and innovation effectively and efficiently in the future. The first is SAFCOL's technological capabilities to develop and beneficiate its biological asset, including and especially increasing its R&D capacity and the productive capacity of its Timbadola Sawmill. The second concerns SAFCOL's 13 social compacts with communities. These compacts could be leveraged, beyond the corporate social investment paradigm, for greater impact with respect to SAFCOL's dual mandate. There is encouraging evidence that SAFCOL is leveraging its community partnerships, particularly in terms of training and eco-tourism. This could be further strengthened through deeper and more focussed engagement on livelihoods, enterprise development and innovation in the informal sector, including working with local, provincial and national government departments, as well as private sector actors, to achieve impact at scale.

SANEDI: The value of stakeholder engagement

The energy sector in South Africa faces a plethora of immediate and long-term challenges, that have been widely reported and discussed in the South African and international public sphere in recent years. By all accounts, most pressing is restoring public confidence and financial health to Eskom, in the context of ageing coal-based generation and transmission infrastructure, the rapidly escalating cost of electricity for individual and commercial consumers, persistent load-shedding, and the legacy of state capture. Longer term, climate change and the demands this places on countries and industries to reduce emissions and adopt renewable energies, represents wider risks and priorities. In current research and policy discourse, this is reflected in the relatively novel concept of the 'just transition' in the context of South Africa's historic minerals-energy complex. Policy uncertainty has been a feature of the South African energy sector, to the extent that subsequent administrations have placed different emphases on components of the country's energy mix. For example, the relative weighting of nuclear to other sources, but also the opening of bid windows for renewable energy projects by independent power producers (IPPs). Out of this uncertainty, arguably, has arisen a situation of policy flux, where policy options are rapidly changed.

On the upside the sector is also characterised by rapidly advancing technological development and substantial opportunities for existing and new actors to participate in the country's energy transition.

Figure 5 illustrates the linkages with formal knowledge producers, such as universities (local and international) and science councils, which enable critical knowledge and information flows. It also showcases linkages between SANEDI and local and international energy regulatory and funding organisations. Notably, the presence of a range of policy frameworks points to the strategic positioning of SANEDI within the South African energy policy environment, an environment it must navigate in terms of its programming as well as its broader organisational strategy. Within the global environment, key framework conditions include climate change, as well as Industry 4.0, both of which already intersect in complex ways with existing policy, economic and governance frameworks. The substantial number of international funders with which SANEDI interacts is perhaps a reflection of an actor well-positioned, both in terms of its mandate, governance, and its capabilities, to deliver value-added outputs in response to the requirements of these actors.

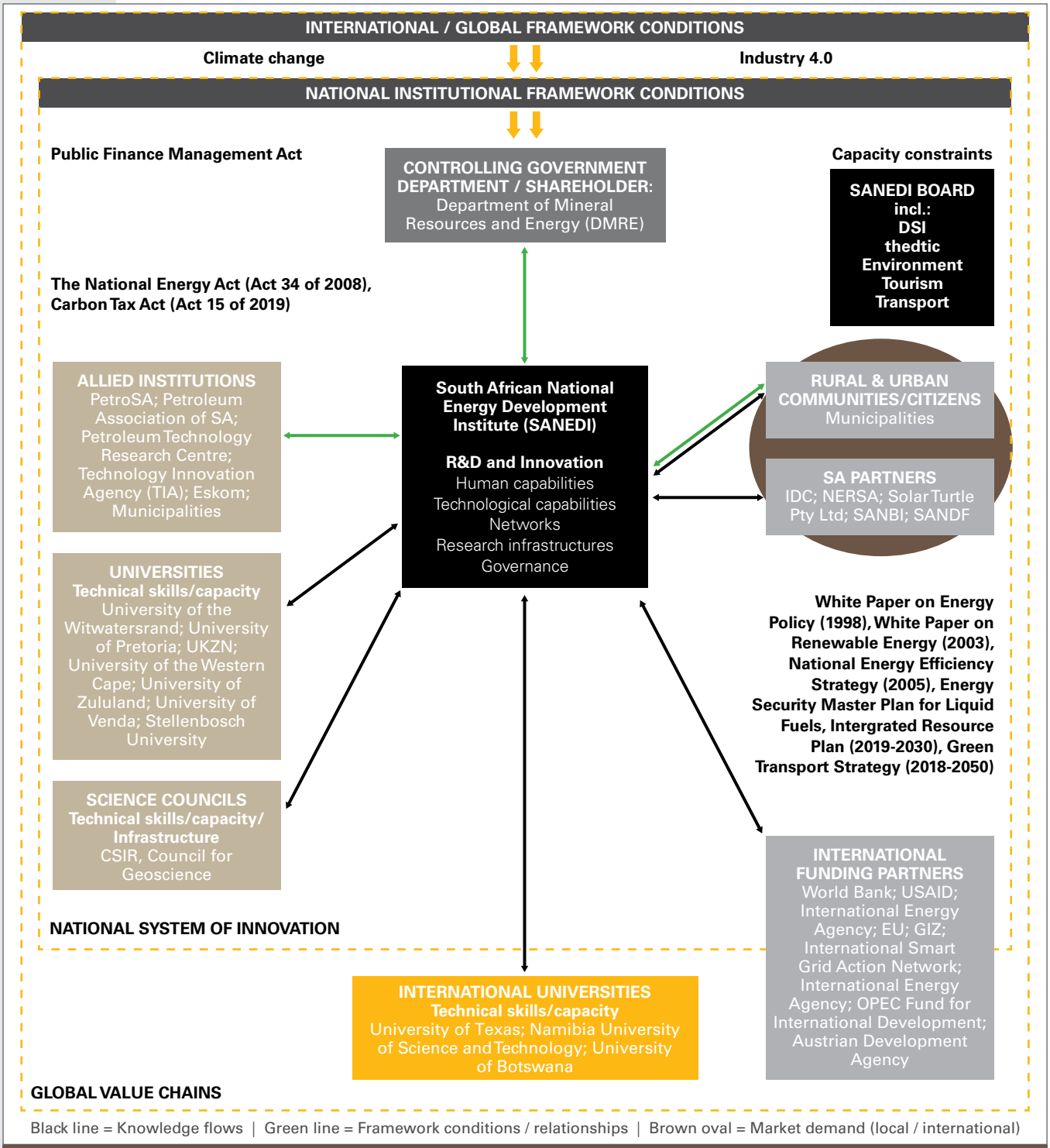


Figure 5: Mapping SANEDI's R&D and innovation system

SANEDI, an SOE wholly owned by the South African government, was formed in 2003 with the primary aim of supporting the South African government to achieve its objectives as set out in the National Energy Act (Act 34 of 2008). It reports to the minister of mineral resources and energy. SANEDI's mission encompasses the use of "applied and energy research and resource efficiency to develop innovative, integrated solutions that will catalyse growth and prosperity." SANEDI aims to foster a culture of greater efficiency and a more rational use of energy, accelerate the transformation to a less energy and carbon-intensive economy and enable informed energy planning, decision-making and policy development.

A dedicated R&D performer, SANEDI has a well-established R&D programme focused on applied energy research and demonstration, with six sub-programmes: Cleaner Fossil Fuels; Smart Grids; Working for Energy; Data and Knowledge Management; Cleaner Transport; and Renewable Energy. Since its formation, SANEDI has built a substantial track record of technological capability within these areas, given expression through several ongoing and completed projects and initiatives. Notable examples include a carbon capture and storage project, currently being implemented in KwaZulu-Natal with substantial investment from the World Bank, a number of smart grid projects aimed at improving the capacity of municipalities to operate sustainable electricity distribution financial models, and an array of rural renewable energy initiatives targeting poor communities.

SANEDI retains a core of R&D personnel, in addition to corporate services staff, comprising key functions such as administration, finance, IT and human resources. Most of SANEDI's R&D personnel are trained engineers or scientists, including leading industry experts previously employed in private and public companies or government departments. As an organisation with a concentration of energy R&D and innovation expertise, SANEDI is a vital site for the development and growth of energy R&D and innovation capability within the South African National System of Innovation, as well as in the field of energy studies within the Global South.

In contrast with larger-scale R&D-performing SOEs, SANEDI has modest research infrastructure that it owns or maintains. Its research infrastructure requirements, nevertheless, are substantial in some project instances. Where it does not own or commission the infrastructure itself, SANEDI accesses research infrastructure in collaboration with universities, non-profit organisations, other SOEs, and municipalities across the country and internationally. It has been intentional in not accumulating a mass of research infrastructure, such as laboratory or demonstration equipment, or software programmes. This strategy compels it to join forces to scale its efforts or experiment with new technological approaches.

Regarding the governance of R&D and innovation, SANEDI's board comprises several senior officials across key line ministries, including the Department of Science and Innovation. For nearly half a decade, interim CEOs have held office, reflecting an ongoing leadership sustainability challenge. This relates closely to the findings of a recent institutional review of SANEDI which recommended that greater attention be paid to the organisation's capacity to sustain its activities financially and locate its value proposition within the energy R&D and innovation landscape. An area with a paucity of information concerns the strategies to be adopted in the commercialisation of SANEDI-owned technologies to ensure public value is derived from the suite of public investments being made by SANEDI and its partners.

The detailed case study argues that collaboration is a critical dimension gearing SANEDI to perform R&D and innovation more effectively to achieve its stated mandate.

As a relatively small and new actor within the busy national and global institutional energy landscape, characterised by both policy uncertainty and dynamism, collaboration and partnership is framed by SANEDI as central to its R&D and innovation capabilities and, by extension, its ability to deliver on its mandate. SANEDI works with a plethora of local partners, and international partners. Partnerships cut across both public and private sectors, and enable SANEDI to share the costs, risks and rewards of joint work, and validate the implementation of new technological solutions within specific community or municipal contexts. The organisational capacity of SANEDI to manage its collaboration portfolio—its partnering function—is codified and includes a stakeholder engagement team as well as accompanying strategy and governance mechanisms to ensure the health and appropriate management of inter-organisational relationships. Collaboration also helps SANEDI's R&D personnel to acquire

new knowledge and build capacity, as well as validate and quality assure its projects. Indeed, SANEDI's strong partnering function can, in part, be attributed to its robust R&D and innovation governance—that is, the effective and supportive management environment that enables the entity to secure the right collaborative partners and funding on an ongoing basis. Equally, a strategic approach, including the appointment of a new CEO beyond interim appointments, is required to ensure the organisation selects the appropriate areas to co-invest or partner in, and does not spread itself too thin.

Towards a scale of gearing

As the description and analysis of each case illustrates, SOEs are heterogeneous in their nature, perhaps especially so when it comes to their R&D and innovation capabilities, as there are no set performance metrics, in contrast to financial performance, for example. What were the similarities and differences that emerged most clearly in the research, and how can we compare the extent to which each SOE is geared?

To understand how an individual SOE functions effectively, five dimensions *within the organisation* were used to guide the empirical analysis. It is proposed that the way in which SOEs function within each of these five dimensions shapes how they leverage R&D and innovation and, therefore, their ability to deliver goods and services.

Table 5 compares how each of the three SOEs are geared for R&D and innovation using a scale to assess their activities within each dimension. The four-fold rating scale ranges from excellent, through good, to work-in-progress and finally challenges experienced.

Table 5: A comparative assessment of gearing for R&D and innovation

Gearing scale

= Excellent **= Good** **= Work-in-progress** **= Challenges experienced**

SOE	Human capabilities	Technological capabilities	Networks	Research infrastructure	Governance
ATNS					
	Trend data shows an increase in R&D personnel and an improved ratio of technicians to researchers, though in-house capacity to perform R&D remains a challenge that ATNS overcomes through collaboration. The development of the ATNS Training Academy provides an excellent example of non-R&D innovation delivered by ATNS.	Technological capability building is characterised by wide-ranging capital investments in new physical infrastructures, systems, technologies for information and communication, training programmes and collaborative networks. An ongoing challenge for ATNS concerns its symbiotic relationships with OEM, which has ramifications for	ATNS engages a wide range of partnerships. Communication networks: These operationalise multinational agreements such as the Chicago Convention (i.e. South Africa assigns a representative to the International Civil Aviation Organization to report back on global industry developments) and ensure ATNS remains abreast	While ATNS has a rich asset base of physical and digital infrastructures, it does not have substantial dedicated facilities for the performance of R&D.	It is clear that ATNS has made substantial efforts to develop a strategy to drive business revenue growth and efficiencies. In the past decade it has positioned innovation, and more recently R&D, as key drivers of growth. A R&D Strategy, which draws in key executives as well as staff across the organisation, focuses on positioning ATNS

Continues overleaf...

SOE	Human capabilities	Technological capabilities	Networks	Research infrastructure	Governance
ATNS					
		the cost of doing business.	of regional and global standards. Skills partnerships: ATNS works collaboratively with universities including the universities of Pretoria and the Witwatersrand, to leverage expertise and create a pipeline of engineers, researchers, executives and technicians. Technology partnerships: ATNS collaborates with state actors, such as the Technology Innovation Agency, CSIR and non-state actors on technology development projects.		in relation to the challenges presented to aviation by the Fourth industrial revolution. Perhaps more than ever before, innovation and R&D are within the crosshairs of ATNS governance actors.
SOE	**Human capabilities**	**Technological capabilities**	**Networks**	**Research infrastructure**	**Governance**
SANEDI					
	SANEDI has a very small R&D team. However, the team is supplemented by collaborative partnerships the SOE has established over the years. These partnerships benefit SANEDI through expertise in the energy sector, research infrastructure, funding, amongst others.	SANEDI undertakes R&D on carbon capture and storage to reduce carbon dioxide emissions into the atmosphere; on information and telecommunication infrastructure to efficiently deliver electricity; and on energy to deliver sustainable renewable clean energy, as well as energy efficiency, climate change mitigation and renewable energy. It has developed an extensive track record of project-based investment	Collaboration is central to SANEDI's R&D and innovation capabilities. SANEDI's 2018-19 annual report notes that SANEDI is partnering with several national and international partners, donor organisations, development partners, South African government departments, academic and research institutions, to leverage financial and knowledge resources to benefit the country. There is a stakeholder	SANEDI accesses research infrastructure through collaboration with universities, science councils, municipalities, and other across the country as well as internationally. Research infrastructure range from databases and modelling software, to municipal electricity control rooms.	SANEDI's effective R&D team and the partnerships it has cultivated is credited with the entity's good R&D and innovation governance. However, more needs to be done to make sure that SANEDI has access to adequate research infrastructure to enable its R&D-led innovation, as well as stable top-level leadership to drive the SANEDI research and innovation agenda.

Continues overleaf...

SOE	Human capabilities	Technological capabilities	Networks	Research infrastructure	Governance
SANEDI					
		and learning within these domains.	engagement strategy, in place approved by the SANEDI board to enable SANEDI to fulfil its mandate and strategic goals. SANEDI depends on its stakeholders for funding, policy development, collaboration, programme development and implementation. As such, SANEDI continues to established partnerships with local and international organisations and institutions.		
SOE	**Human capabilities**	**Technological capabilities**	**Networks**	**Research infrastructure**	**Governance**
SAFCOL					
	SAFCOL's R&D team is less than 1% of the entity's overall workforce. Non-R&D based innovation activity employs a broader range of personnel with service roles, such as eco-tourism and training. The SAFCOL training academy provides a wide range of programmes for both employees and communities within the SAFCOL catchment. It also supports sector capacity building through a post-graduate student bursary scheme.	Key technological capabilities developed by SAFCOL include through its timber and non-timber operations. Its timber capabilities span the entire value chain, from genetic engineering and breeding to sawmilling and beneficiation of timber products. Its non-timber capabilities encompass community-based forestry, training and eco-tourism.	SAFCOL attempts to foster proactive networking and collaborative activities with universities, research councils, communities and global and local organisations. Collaboration helps SAFCOL to solve different kinds of operational problems, is valuable for the capacity development of its researchers and the organisation more broadly, and helps to grow its relationships with the communities in which it works.	SAFCOL has dedicated facilities for the performance of R&D, including a nursery and R&D centre. The centre is equipped with state-of-the-art equipment, with more to come on stream. Procurement remains a challenge and collaboration is used to fill gaps.	R&D has been identified as a key opportunity for SAFCOL in its recent integrated reports. This has been underpinned by continued investment in R&D at SAFCOL, as well as the incorporation of an innovation portfolio within its executive structure. Concerning perhaps, from an innovation perspective, is that SAFCOL has not achieved capital investment KPIs; and does not appear to have a strategy for intellectual property management or technology transfer.

Source: Case study reports on SANEDI, ATNS and SAFCOL. CeSTII Working Papers 2b, 2c and 2d.

This gearing scale provides a number of valuable insights.

First, similarities between SANEDI and SAFCOL in terms of their pattern and degree of gearing are revealed, in contrast to ATNS. Each was 'excellent' on only one dimension—for ATNS, on institutional governance, and for SANEDI and SAFCOL, in terms of their networks. Each was rated 'good' on two dimensions: for ATNS, on human capital and networks, for SANEDI and SAFCOL on technological capabilities and institutional governance. Likewise, a 'work in progress' assessment applied to two dimensions for each SOE studied, with a common concern about research infrastructure: for ATNS, on technological capabilities and research infrastructure and for SANEDI and SAFCOL on human capital and research infrastructure.

In general, it can be concluded that while the SOEs incorporated R&D and innovation activities within their strategic outlooks, and had clear examples of performance, there were dimensions in which each could be more appropriately geared—capacitated, resourced, organised—to improve the contribution of R&D and innovation to their overall efficiency and effectiveness.

Second, it is possible to analyse the data across the three cases, to gain insight into how each of the five dimensions contributes to gearing the SOE for innovation.

Human capabilities

Each SOE has a unique configuration of human capabilities that make up the R&D and innovation core of the organisation. These include highly skilled engineers, technicians, managers and executives. In all three cases, an impressive composition of skilled personnel and projects is a notable feature, but the specific nature of the teams is distinct.

In the case of SANEDI, R&D is the core business of the entity and the team is centrally positioned. In the case of SAFCOL and ATNS, R&D supports and develops the core business. As such, R&D within SAFCOL and ATNS occupies a more peripheral position within the organisational structure, even if strategically R&D is considered central to future performance. The positioning places different demands on R&D personnel and support staff, such as managing competing demands for resources, ensuring the sustainability of positions that may be dependent on external funding, and clarifying the overlapping roles and responsibilities of managers and researchers.

Technological capabilities

Technological capability building concerns the accumulated knowledge of an organisation in relation to the technologies it has developed, or uses. In the case of SAFCOL and ATNS, deep technological capabilities have been established since aviation and forestry were introduced in South Africa during the colonial and apartheid periods. SANEDI has a long history of energy R&D extending back into its predecessors' organisational histories.

One of the challenges all three face is how to leverage technological capabilities, through for example IP transactions, to drive revenue growth from innovation. In the case of SAFCOL, a key challenge—and opportunity—is how to diffuse technological capabilities beyond the immediate remit of the organisation, to the communities which share the forestry environments in which SAFCOL works.

In the case of SANEDI, a critical challenge is how to ensure that the mandate of commercial utilisation of IP is realised from its swathe of projects. For ATNS, the substantial technological capabilities of the organisation are in the process of being commercialised through different technological and training consultancy projects, however, it does not have a clearly delineated approach to the protection and utilisation of IP.

Networks

Performance in the dimension of networks was excellent or good, and all three SOEs had strong collaboration portfolios. Overall, there is evidence in all three cases of strong systemic linkages between the SOEs and other actors within their sectoral systems of innovation.

Interaction, and the resulting information and knowledge flows, is a critical driver of both R&D and innovation. Collaboration plays different roles, but generally, its purpose is one of three: access to knowledge, expertise and skills; access to technologies or research infrastructures; and access to new sources of information or regulatory standards. Collaboration can also allow the entity to leverage financial resources, as in the case of SANEDI.

All SOEs provided examples of recent events used to catalyse and enhance their networking. In the case of ATNS it was the Avi-Afrique Innovation Summit; in the case of SAFCOL, the Forestry Industrialisation Conference in 2017 and in the case of SANEDI, an energy round-table at a recent Mining Indaba.

There was a conscious awareness among the executives and researchers about the value and benefits of linkages, but also their risks and costs. The cases suggest that SOEs need to be well organised internally to take optimal advantage of these linkages.

Research infrastructures

Research infrastructures, whether virtual data sets, physical facilities, or network infrastructures play a critical role in national and global systems of innovation. While SAFCOL has dedicated research infrastructures (a laboratory, a nursery), neither SANEDI nor ATNS conduct R&D from custom-built laboratories. In the case of ATNS, R&D is performed on-site using the equipment on which its service provision is based. It could be argued that this is a type of research infrastructure. In the case of SANEDI, infrastructures are accessed through partnerships with universities and research institutions. Commitment to long-term investment in research infrastructures through capital expenditure programmes, was one common area that could be strengthened across all three SOEs.

Governance

The South African corporate governance landscape has changed markedly since the first King Commission report (1994). In this context, state capture poses a significant risk to the performance of SOEs in South Africa, which face declining public confidence and increasingly scarce resources from a strained fiscus. The governance of R&D and innovation specifically —as the engines of future business growth—is therefore a critical issue for policy makers, customers and end users.

In this sense, good governance extends beyond simple compliance with bureaucratic requirements, but requires a proactive approach to the stewardship of expertise and infrastructures in the public interest.

In all three cases, R&D strategies articulated by the SOEs, take form in programming choices, decisions to partner, and in eventual research results. In the case of ATNS, a new R&D strategy is a feature of its governance landscape, while for SANEDI and SAFCOL, long-standing R&D programmes are beginning to be (in the case of SANEDI)—or need to be (in the case of SAFCOL)—enhanced by more proactive approaches to innovation and the commercialisation of intellectual property.

Informing a set of indicators

This section demonstrated the analytic value of the conceptual framework, particularly the use of the five dimensions to assess the R&D and innovation gearing of the SOEs. The next section uses these insights to inform a proposed set of indicators.

4 | FRAMEWORK AND INDICATORS TO MEASURE R&D AND INNOVATION AT SOEs

This section proposes a framework to measure how geared SOEs are for R&D and innovation (see **Table 6**). This includes a comprehensive set of recommendations for governance indicators. For indicators to be widely accepted they must be simple, easy to create and make strategic sense for a wide range of SOEs operating in very different sectoral systems of innovation. Even with the limitations on generalisability due to a limited set of cases, sufficient insights have been derived from the analysis of the three cases to serve as the basis for proposing the set of indicators that follow.

A framework for assessing R&D and innovation across SOEs

The proposed framework identifies the dimensions that should be measured, and motivates why each is important. It then lists possible indicators that are currently available, or may be relatively easily collected. Many of these potential measures will apply to all SOEs, but there will be indicators that are not applicable to specific SOEs.

Finally, the framework proposes a single proxy indicator for each dimension, one that is most widely applicable is proposed for inclusion in the compact agreements with the SOEs and their boards.

A caveat is required in relation to the proposed metrics as they represent a mix of input, output and outcome indicators that aim to measure innovation in SOEs, without reference to a particular theory of change. This generality is necessary because of the sector-specific heterogeneity of SOEs, as well as the heterogeneous nature of the strategies that individual SOEs may pursue.

Other indicators on the general functioning of SOEs were outside the scope of this study, and may need to be included for a full suite of metrics in future.

There are two main distinctions in the types of focal dimensions. First, a set of indicators are required to measure R&D and innovation activities, including technology transfer activities. **Table 6** proposes a pool of input and output measures for which data is typically available, from which metrics may be selected.

The second type of dimension relates to the internal organisational conditions that facilitate, enable and constrain R&D and innovation activities in SOEs. Here, the five dimensions provide a useful conceptual logic, with their value reinforced by the comparative analysis.

There are also two types of indicators. Growth indicators are measured as a year-on-year percentage indicator. Proportional indicators are measured as a relative proportion of an underlying quantity.

The following sections consider each of these in turn, and provides motivations for the selection of the specific metric.

Table 6: Indicators to measure the innovative potential of SOEs

Dimensions measured	Why important	Indicators	Metrics
R&D and innovation activities			
R&D performance	The extent to which resources are dedicated to R&D	• R&D expenditure over time • R&D spend as a proportion of total firm budget • Type of R&D conducted (basic, applied, experimental)	• R&D expenditure as a percentage of income generated • Proportion applied to experimental R&D
Innovation performance	The extent to which resources are dedicated to innovation	• Innovation expenditure • Type of innovation • Business improvement due to innovation	• Innovation expenditure as a percentage of income generated
Intellectual property	The extent to which knowledge protected and commercialised	• Patents • Plant breeders rights • Trademarks / Copyrights • Licenses • Revenue generated from licensing	• Growth in number of patents granted, or plant breeders rights granted
Conditions that enable, support and facilitate R&D and innovation			
Human capabilities	Human resources dedicated to R&D and innovation	• Human resources dedicated to innovation • Human resources dedicated to R&D • Type of HR • Qualifications • Training facilities	• Growth in human resources dedicated to R&D and Innovation • Proportion of technicians relative to researchers/ scientists/engineers
Technological capabilities	A history of capability within a particular technological domain is a potential area of strength for technological innovativeness	• Technologies that the firm historically has proficiency in	• Growth in investment in new technology, in real terms
Research infrastructure	The maintenance and renewal of research infrastructure is a necessary element for current and future knowledge generation	• R&D expenditure on equipment etc. • Research facilities and infrastructure • Cooperative agreements around infrastructure	• Expenditure on equipment, land and buildings for research as a percentage of R&D expenditure

Continues overleaf...

Dimensions measured	Why important	Indicators	Metrics
Conditions that enable, support and facilitate R&D and innovation			
Linkages, collaboration and networks	Linkages to support R&D and innovation	• Linkages with national/ regional/global partners • Cooperation around training • Cooperation around research infrastructure • Cooperation around research • Cooperative agreements around training	• Growth in number of cooperation partners
Governance	Integration of R&D and innovation in business strategy	• Does the SOE have an R&D strategy? • Does the SOE have an innovation strategy? • Does the SOE have an IP and technology commercialisation strategy? • Is R&D included in the performance compact? • Is there a dedicated R&D structure within the SOE? • Is there a dedicated innovation structure within the SOE? • Is there a dedicated IP protection structure within the SOE? • Does the SOE have a legal framework within which it can commercialise products?	• Income generated from non-core SOE activities as a percentage of all income generated

Source: Case study reports on ATNS, SANEDI and SAFCOL. CeSTII Working papers 2b, 2c, 2d

Indicators on R&D and innovation activities

There are three dimensions important to measure here—R&D, innovation and technology transfer activities and performance. It is important to have performance measures that assess the extent to which resources are devoted to R&D and innovation and to protecting and commercialising proprietary knowledge or technology created in the process. There are a range of possible measures available. For example, for R&D there is readily available data from the national R&D surveys, on R&D expenditure over time, and as a proportion of the total SOE budget. There is also data available on the type of R&D conducted, as the relative balance between experimental, applied and basic research may become increasingly significant. Similarly, in relation to innovation, SOEs may have data on innovation expenditures, the type of innovation they conduct or the outcomes of innovation for the enterprise. The dimension of technology transfer is relatively neglected, and few SOEs routinely gather data in this regard. However, it is not difficult to collate enterprise level data on the number of patents, licences, trademarks or plant breeders rights applied for or awarded in a specific year. Another option is to calculate the revenue generated from these activities.

The metrics chosen here for inclusion as proxies that quantify the relative importance attached to R&D and innovation were R&D and innovation expenditures as a percentage of income generated. These are typically considered as input indicators for processes that derive output from R&D or innovation activities. We chose income generated, instead of turnover or sales as the denominator in these metrics because some SOEs do not derive their income from revenue gain from goods and services, but instead from government allocations alone.

Generally, SOEs do not perform basic research. The level of expenditure on experimental development relative to applied research is a proxy measure of the emphasis an SOE places on getting innovative products (perhaps derived from an R&D process) to the market, as opposed to the more day-to-day R&D required for maintaining proper functioning for the services it provides.

To quantify the level of importance attached to IP protection, the selected proxy indicators are patents granted, or plant breeders rights granted. Plant breeders rights are significant in the South African context, given the natural advantage in the fields related to biological products. These are often considered as output indicators, or intermediate output indicators, in simple theories of change for commercialisation of innovation products. However, the output of such IP protection mechanisms depends on the strategies that firms adopt when it comes to IP management and utilisation. Many firms may use the acquisition of IP as an input to an innovative activity, for example in reverse engineering applications.

Indicators on conditions that enable, support and facilitate R&D and innovation

Based on the analytical dimensions of firm performance in sectoral innovation systems, together with insights from the comparative analysis of the cases in Section 3, it was possible to extract a pool of possible indicators for each of the five dimensions.

With regard to **human capability** development, an important element is the level of technical and scientific skills as well as the proportion of technicians supporting researchers and engineers. There are a number of measures available that are routinely collected in the national R&D surveys, such as the human resources dedicated to R&D, the type of human resources available—researchers, engineers and technicians—and the levels of qualifications of these. By extension, such measures could be extracted for innovation activities other than R&D. Moreover, the case study research suggested the importance of other potential measures, such as a count of the establishment and maintenance of a training institution, to meet sector-dependent qualification needs. Two possible measure are proposed here: growth in human resources dedicated to R&D and innovation, and the relative proportion of technicians supporting researchers and engineers.

It is important to measure **technological capability**, because a history of capability within a particular technological domain is a potential area of strength for innovation. The technological capability of any single SOE is usually easily identified. These specific technological histories are a source of potential competitiveness. A greater embrace of other sources of technological ability within the national system of innovation from public research institutes or universities may improve the overall functioning of the system. The proposed indicator would measure growth in investment in technology, in real terms.

Expenditures on the maintenance and renewal of **research infrastructure** is a necessary element for current and future knowledge generation, and hence, critical to measure. Dynamism in each sector will depend on growth in these investments into future innovations. The case study analysis suggests this is a key area for strengthening the functioning of SOEs. Potentially available measures from the R&D surveys include expenditure on the acquisition of new equipment, land, etc. and the cost of maintaining such infrastructure. Other data is potentially available from the national research infrastructure audit process. New data that may be collected is a list of cooperative agreements around shared infrastructure. The specific metric proposed is to calculate the proportion of expenditure on equipment, land and buildings for research as a percentage of R&D expenditure, on the grounds that it is readily available.

The sectoral systems of innovation mapping process and the case study analysis highlighted the significance for R&D and innovation of well-established local and international **linkages, collaboration and networks** with expert partners within their sector of activity. The number and quality of interactions generally would have the effect of strengthening the sectoral—and national—systems. All the SOEs studied showed well-established local and international linkages with expert partners within their sector of activity.

Here there is little well established data that can be drawn on. It may be necessary to require SOEs to record their linkages with national, regional and global partners, and where there are formal cooperative agreements. It may also be useful to distinguish the types of cooperative interactions, whether around training, research infrastructure, research or innovation. As a single metric, it is proposed that SOEs record the annual growth in the number of cooperation partners.

In terms of **governance**, it is critical to assess the integration of R&D and innovation in the enterprise strategy. The case studies illustrate the importance of assessing whether the SOE has an R&D/innovation/technology transfer strategy, whether these are included in the performance compact, and whether there are dedicated internal structures to support and promote R&D and innovation.

The institutional relationships of SOEs are shaped by the legislative frameworks governing their activities, particularly non-core activities that are not mandated, but potentially income-generating. They also operate within the constraints of local and international standards that regulate the behaviour of actors in the specific sector of activity. This requires adherence to the strategic imperatives set by the parent governing body, as well as the active management of government reporting requirements.

A key indicator of innovation is the gain an enterprise makes entering new markets. As a measure of success in realising this strategic focus, given adherence to the reporting requirements, the measure proposed is the growth in revenue from commercial activities that are non-core to the SOE, relative to the income generated from its core activity. Prudence is required, in that if the non-mandate activity becomes routine, it would no longer measure innovation outcomes.

Towards a set of indicators

Taken together, these metrics cover the essential elements necessary to monitor and evaluate R&D and innovation performance in SOEs, and the organisational conditions that are likely to support and promote them. They are proposed as the basis for consultation and discussion with SOEs and their shareholder departments, around common standards that can be adopted for reporting over the medium term.

CONCLUSION

It is usual to conclude by setting out the value of the research and its limitations, as well as directions for future research.

Value and limitations of research

State-owned enterprises (SOEs) are important national stakeholders with a mandate to contribute to sustainable economic growth and South Africa's broad developmental goals. In their diversity, SOEs have the potential to stimulate employment creation and provide important structuring elements supporting economic growth through transportation networks, bulk infrastructure, energy and ICT infrastructure. South African SOEs provide vital services for businesses to function more cost effectively, and provide affordable services to individual citizens and communities alike.

The value of the research is that it has identified many of the dimensions necessary for effective R&D and innovation, through a comparative analysis of three cases. The SOEs have a historical technological capability built up over years of performing R&D within their sector. They are embedded in networks at both the local and international level. They have good linkages with universities and public research institutes, especially related to sourcing of young technically-skilled talent. The level of personnel engaged in R&D and innovation is low, and needs to be increased in line with new R&D or innovation projects. Future growth in R&D and innovation activity will require good maintenance and new acquisition of research infrastructure, as a critical determinant.

The strategies that SOEs apply to generate income from non-mandated activities range from training institutions to expansion of services outside of South Africa. Although they may have expressed their need for an IP protection strategy, or may be developing such, the SOEs studied had not adopted IP strategies as a means to commercialise their innovations.

The limitations of the research were highlighted at the outset—that any conclusions it draws are based on generalisation from only three case studies—hence, recommendations must be preliminary. This is especially true due to the heterogeneity of SOEs, dictating caution in generalisation even if a more comprehensive set of cases had been analysed.

Nevertheless, the design of a set of indicators that can drive the desired change in SOEs and in the national system of innovation is urgent. The draft set of indicators proposed can form the basis for future stakeholder and policy-maker discussions towards the desired final indicator set.

Hence, the value of the research is the mirror opposite of this caveat, particularly given the paucity of empirical research on how SOEs are leveraging R&D and innovation.

In-depth qualitative case studies guided by a clear conceptual framework can provide rich insights to inform the design of a simple set of metrics to be included in stakeholder compacts, within the bounds of current resources and datasets.

Directions for further research

More research and consultation is required to inform the design and implementation of such a performance measurement framework and specific measures including:

- More in-depth case studies, particularly of the barriers and constraints experienced in the larger SOEs whose activities are so critical to meet developmental mandates in South Africa
- A process of stakeholder engagement around the proposed framework and metrics, to ensure legitimacy and validity of the final selection
- An investigation of existing datasets and how they may be made available, to inform the design process
- Working definitions and calculations to create the selected metrics.

Ultimately, the framework and metrics remain proposals and recommendations, based on the available evidence. However, they provide a good start.

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APPENDIX A: INTERVIEW SCHEDULE

Strategic Manager: Interview questions

Dimension	Description	Questions
Human capabilities	Human capabilities and skills are an enormously important aspect of an R&D + innovation system. Human capabilities have to do with what individuals are able to do or are capable of doing (that is individual's skills, knowledge and expertise). They are very important for a company's performance, skill acquisition, learning and knowledge management. Technical capabilities also help in seeding knowledge, as well as mentorship to young scientist. Technical capabilities allow organisations or entities to translate research discoveries to impactful outcomes.	• Innovation can encompass the introduction of new or significantly improved/changed products and/or business processes. Can you tell us about the individuals, other than R&D + innovation staff/personnel, within your organisation, who are working on innovation? • Are there any skills gaps when it comes to innovation? How do you fill these?
Technological capabilities	The ability of the firm to execute any relevant technical function. Technological capabilities are closely associated with internationalisation of product lines.	• To what extent are your technological capabilities enabling innovation in your organisation? • What strategies / plans do you have in place for the development of your organisation's technological capabilities?
Networks	Collaboration refers to working collaboratively with R&D + innovation institutions. These institutions could include science councils, universities, private firms, professional bodies, other SOEs and other organisations. Collaboration, formal/informal, has the potential to increase R&D + innovation productivity, and help in transferring skills and expertise.	• What networks do you use to promote innovation in your organisation? • How do you access these networks? What benefits do they bring to your organisation? • Do you have a dedicated mechanism for networking?
Research infrastructure	Research infrastructure refers to resources, facilities and related services that are needed to conduct top-level research in different fields (building/land) etc. It also covers scientific equipment or sets of instruments; knowledge-based resources such as collections, archives or structures for scientific information; enabling information and communications technology-based infrastructure such as computing, software and communication. SOEs require access to good research infrastructure in order to conduct	• In what ways does your entity's research infrastructure enable innovation (product/process)?

Continues overleaf...

Dimension	Description	Questions
	cutting-edge research which in turn nurture and sustain the R&D + innovation and innovation capabilities of SOEs.	
Governance	Corporate governance refers to the systems, processes, policies and structures needed to direct and control companies. This definition suggests that the responsibility for the corporate governance of SOEs lies with the boards of directors, management and supervisors of such companies. Corporate governance is growing into an important tool for building successful, sustainable organisations and enterprises. South Africa's SOEs are subject to the Companies Act of 2008 and the Public Finance Management Act.	• Can you describe the extent to which / how your entity's corporate governance is enabling the efficient and effective performance of R&D + innovation and the achievement of your R&D + innovation goals/ strategies? • Can you maybe share some of the challenges your R&D + innovation department faces in terms of the governance of the entity? • What is your view on the role of the SOE in the face of a high-tech industrialising economy?

R&D Manager: Interview questions

Dimension	Description	Questions
Human capabilities	Human capabilities and skills are an enormously important aspect of an R&D + innovation system. Human capabilities have to do with what individuals are able to do or are capable of doing (that is individual's skills, knowledge and expertise). They are very important for a company's performance, skill acquisition, learning and knowledge management. Technical capabilities also help in seeding knowledge, as well as mentorship to young scientists. Technical capabilities allow organisations or entities to translate research discoveries to impactful outcomes.	• Can you briefly tell us about the educational levels [R&D + Innovation Survey data] / educational backgrounds / distribution of knowledge fields of the professionals who work in R&D + innovation activities in your organisation? • Can you briefly tell us about the talent pools (e.g. universities, private labs, etc.) from which you recruit staff for your R&D + innovation team? • How is your R&D + innovation team organised/structured? • Are there any in-house or outsourced training programmes offered to those who work in R&D + innovation department? If yes, can you tell us about these. • In your R&D + innovation team, do you have personnel with technical expertise that support your R&D + innovation team? [R&D + innovation survey] Can you briefly tell us about any programmes for the development of your technicians skills/capabilities?

Continues overleaf...

Dimension	Description	Questions
		• Are your technicians predominantly local South Africa residents or international communities (foreign internationals from other African countries and abroad)?
Technological capabilities	The ability of the firm to execute any relevant technical function. Technological capabilities are closely associated with internationalisation of product lines.	• To what extent are your technological capabilities enabling R&D in your organisation?
Networks	Collaboration refers to working collaboratively with R&D + innovation institutions. These institutions could include science councils, universities, private firms, professional bodies, other SOEs and other organisations. Collaboration, formal/informal, has the potential to increase R&D + innovation productivity, and help in transferring skills and expertise.	• Can you describe the institutions/organisations/ firms/etc that your organisation collaborates with on R&D + innovation? Can you describe any benefits of working collaboratively with those institutions? • Can you tell us about some of the R&D + innovation topics/ projects you are collaborating on with partners? These collaborations could involve commercial ventures such as the development of new products or the penetration of new markets. • Do you have any specific R&D + innovation collaborations with universities/science councils? Can you tell us about why you chose these partners? • Do you have a management structure/any formal processes for managing R&D + innovation collaborations?
Research infrastructure	Research infrastructure refers to resources, facilities and related services that are needed to conduct top-level research in different fields (building/land) etc. It also covers scientific equipment or sets of instruments; knowledge-based resources such as collections, archives or structures for scientific information; enabling information and communications technology-based infrastructure such as computing, software and communication. SOEs require access to good research infrastructure in order to conduct cutting-edge research which in turn nurture and sustain the R&D + innovation and innovation capabilities of SOEs.	• What types of research infrastructure/ equipment does your entity have to perform R&D + innovation and innovation activities? • Does your entity buy them locally or abroad? • Can you tell us about any plans/strategies for upgrading/ improving/strengthening your research infrastructure in the future?

Continues overleaf...

Dimension	Description	Questions
Governance	Corporate governance refers to the systems, processes, policies and structures needed to direct and control companies. This definition suggests that the responsibility for the corporate governance of SOEs lies with the boards of directors, management and supervisors of such companies. Corporate governance is an important tool for building successful, sustainable organisations and enterprises. South Africa's SOEs are subject to the Companies Act of 2008 and the Public Finance Management Act.	• Can you describe the extent to which / how your entity's corporate governance is enabling the efficient and effective performance of R&D + innovation and the achievement of your R&D + innovation goals/ strategies? • Can you maybe share some of the challenges your R&D + innovation department faces in terms of the governance of the entity? • What is your view on the role of the SOE in the face of a high-tech industrialising economy?

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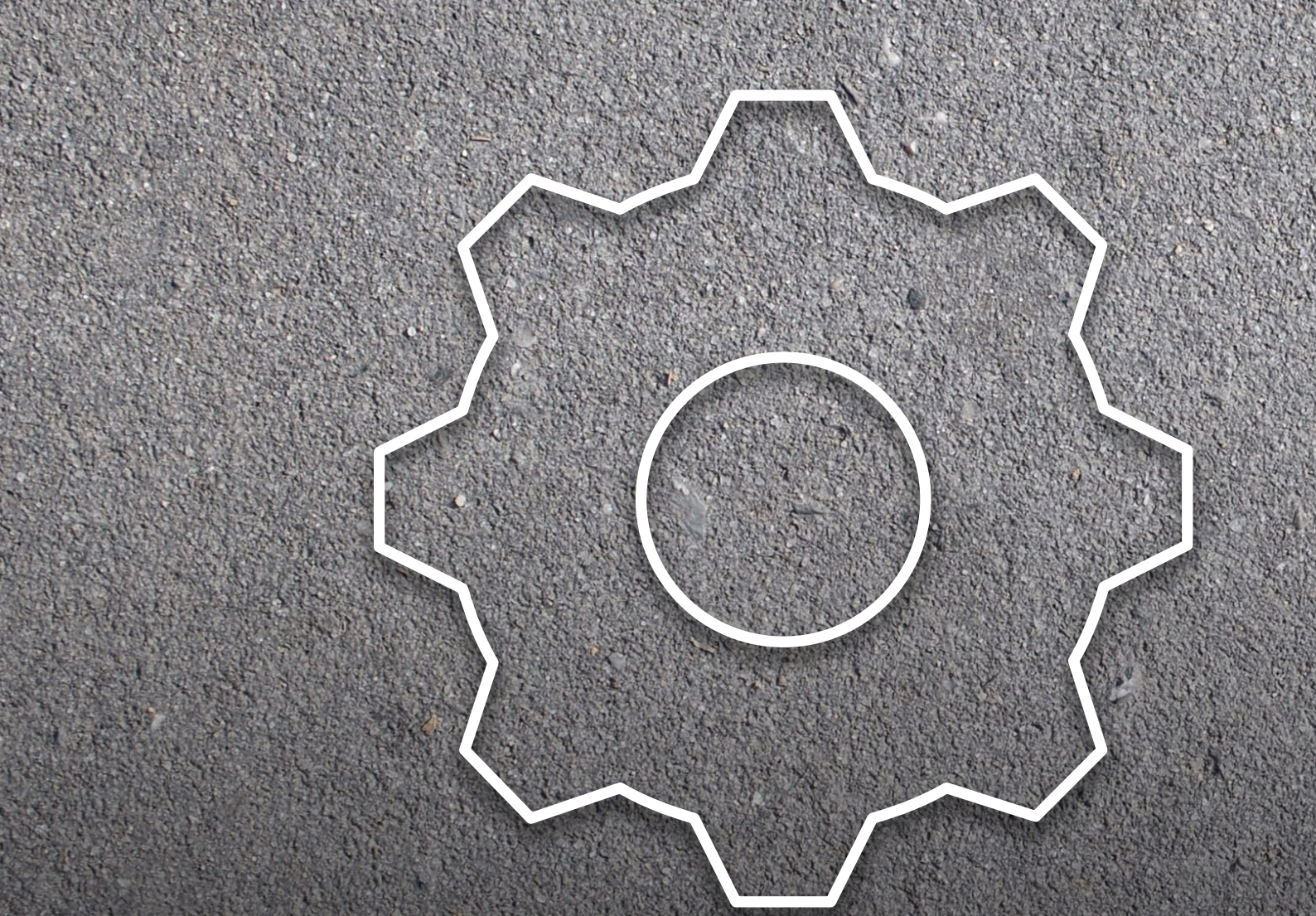

Working Paper Series on R&D and Innovation Capabilities in South African State-Owned Enterprises

State-owned enterprises (SOEs) are important national assets with a mandate to contribute to sustainable economic growth and South Africa's broad developmental goals. In March 2019, the Department of Science and Innovation (DSI), published the White Paper on Science, Technology and Innovation. This recognised the importance of SOEs in the South African economy and the need to revitalise them to play a meaningful role in South Africa's science, technology, innovation and economic development. As key institutions for human capital development and international and national knowledge sharing, the White Paper also aimed to position SOEs as innovation-driven for the knowledge economy. But to what extent and how are South African state-owned enterprises geared to perform R&D and innovation? Based on in-depth case study research with three SOEs—SANEDI, ATNS and SAFCOL—as well as analysis of the academic literature, the Human Sciences Research Council's Centre for Science Technology and Innovation Indicators (CeSTII) identified dimensions key to effective R&D and innovation 'gearing' by these SOEs, including: human capabilities; technological capabilities; networks; research infrastructure; and governance. Out of this research, indicators on R&D and innovation are also proposed to guide national policy discussion on the future of SOEs in South Africa.

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