SYNTHESIS REPORT

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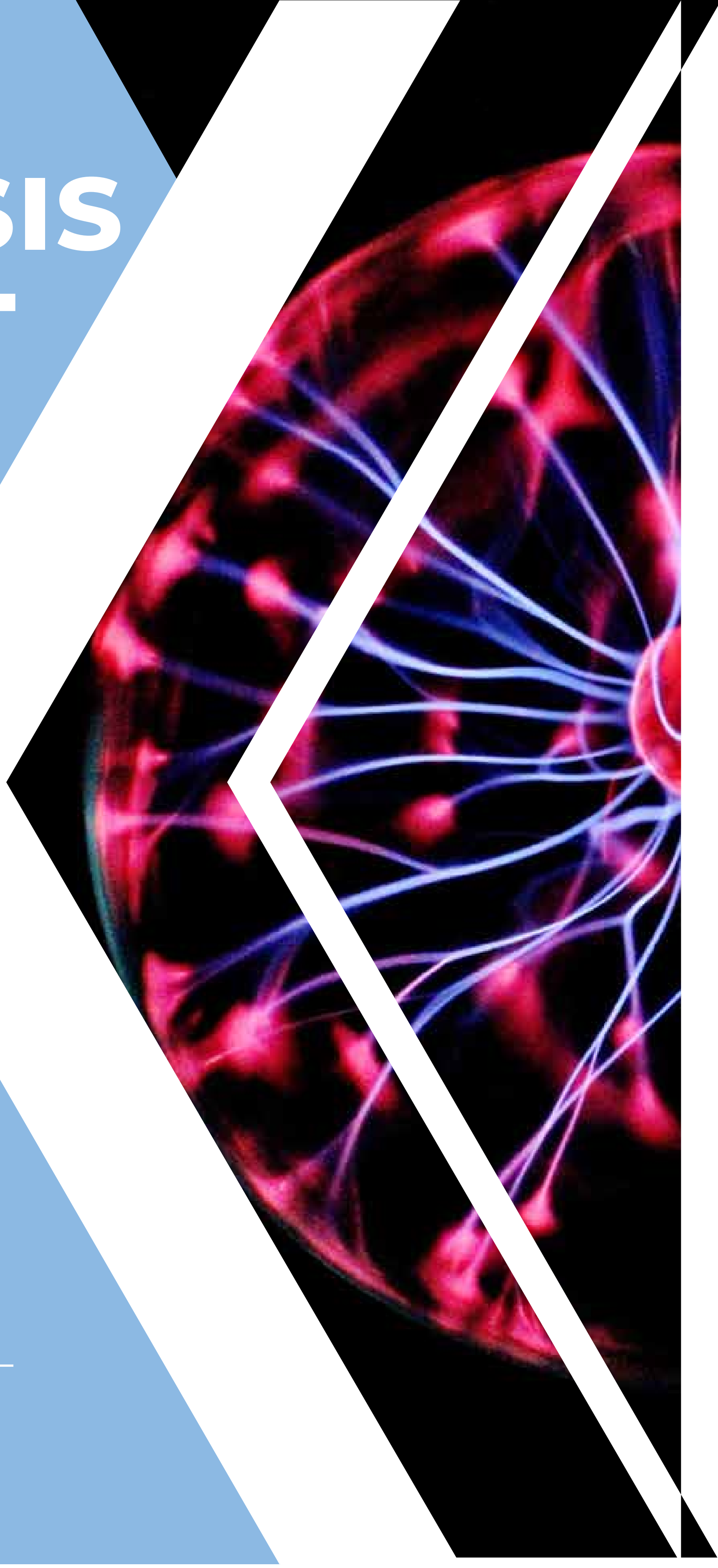

SOUTH AFRICA FORESIGHT EXERCISE FOR SCIENCE, TECHNOLOGY AND INNOVATION

2030

science & innovation

Department:
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REPUBLIC OF SOUTH AFRICA

NACI
NATIONAL ADVISORY COUNCIL ON INNOVATION

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innovation
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CHAIRPERSON'S FOREWORD

This synthesis report was written as part of the South African Foresight Exercise for Science, Technology and Innovation 2030 (SAForSTI), led by the National Advisory Council on Innovation (NACI) as part of its contribution to the development of a decadal plan for implementing the 2019 White Paper on Science, Technology and Innovation. The exercise sought to investigate the future of science, technology and innovation (STI) in South Africa, and the potential of STI to address ongoing societal challenges (including unemployment, poverty, inequality, health and education) and support the creation of inclusive and sustainable socio-economic development. Societal challenges are systemic in nature and require long-term planning and a broad, holistic approach. At an international level, these challenges been articulated as the Sustainable Development Goals (SDGs) in the United Nations 2030 Agenda for Sustainable Development, an urgent call for action. The SDGs need to be addressed and achieved in an integrated fashion, and the emphasis should therefore be on interlinkages, collective actions, coordination and collaboration between different nations, institutions and policies.

Throughout the foresight exercise, it was emphasised that, before a sustainable and just economy could even be discussed, there should be a broader understanding of both inequality (and its economic, gender, spatial and class dimensions, among others) and sustainability. Knowledge has been identified as important for the required transformation to an equitable society and a sustainable economy. Among other things, knowledge is needed to inform policy, which will require bringing together different areas of STI, with all their various economic, environmental and social dimensions, and their potential to create new growth for South Africa.

While the foresight exercise was obviously not aimed at developing concrete implementation plans, the adoption of the STI domains and thrusts it proposes (even in a modified form) as priorities for the next decade will require the system to continue to focus on capacity building (human and infrastructure), develop more effective ways to combine resources (both public and private), develop cooperative solutions, and deploy the many STI resources at its disposal. There may also be implications for knowledge production, policy governance (for instance, ensuring two-way alignment between innovation policy and other policies), policy design and funding.

SAForSTI lays the foundation for the regular foresight studies envisaged in the 2019 White Paper on STI. The synthesis report, prepared by the NACI Secretariat (Dr Mlungisi Cele and Dr Petrus Letaba), benefited from substantive inputs from leading foresight experts Mr Peter Greenwood and Ms Tina James (Non-Zero-Sum Development), and Dr Alexander Sokolov and Dr Ozcan Saritas (Institute for Statistical Studies and Economics of Knowledge (ISSEK) at the National Research University Higher School of Economics in Moscow).

The synthesis report distils the findings of various analyses and reviews, including the following:

- Surveys of global and local STI trends by ISSEK and Non-Zero-Sum Development.
- Situational Analysis: Innovation Theory, Practice and South African Context – D Walwyn et al. (2016).
- 2016 NACI Synthesis Report: Review of the White Paper on Science and Technology and High-Level Framing for a New Decadal Plan.
- 2017 NACI Situational Analysis.
- 2017 NACI Review of the Performance of the South African National System of Innovation 1996-2016.
- Several stakeholder workshops (2018 and 2019) and web-based surveys conducted by Non-Zero-Sum Development.
- Big data analytics from ISSEK for the South Africa Foresight Exercise for Science Technology and Innovation 2030.
- Stakeholder interview data and preliminary versions of profiles of the comparative performance of the research enterprise in several economic sectors were provided by the Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy (SciSTIP).

The synthesis report profited from discussions and input from NACI Council members and a range of national system of innovation (NSI) actors who participated in workshops, web-based surveys, interviews and expert-led groups. In addition, inputs were received from senior government officials and some Technology Top 100 companies. Several experts assisted with the review of inputs generated through workshops and web-based surveys, and the refinement of the draft domains and thrusts identified in the foresight exercise.

NACI gratefully acknowledges support for the project provided by the Minister of Higher Education, Science and Technology and the Director-General of Science and Innovation.

Dr Shadrack Moephuli
Interim NACI Chairperson

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LIST OF ABBREVIATIONS

- 4IR	4th Industrial Revolution
- ABET	Adult basic education and training
- AI	Artificial intelligence
- BRICS	Brazil, Russia, India, China and South Africa
- CE	Circular Economy thrust
- ECD	Early childhood development
- ED	Education for the Future thrust
- EN	Energy thrust
- FS	Future of Society thrust
- GDP	Gross domestic product
- GM	Genetically modified
- HE	Health Innovation thrust
- HT	High-Technology Industrialisation thrust
- ICT	Information and communications technology
- IoT	Internet of Things
- IT	ICTs and Smart Systems thrust
- NDP	National Development Plan 2030
- NSI	National system of innovation
- NU	Nutrition Security thrust
- R&D	Research and development
- RDI	Research, development and innovation
- SADC	Southern African Development Community
- SDGs	Sustainable Development Goals
- SMMEs	Small, medium and micro - enterprises
- SOE	State-owned enterprise
- STEM	Science, technology, engineering and mathematics
- STI	Science, technology an innovation
- UN	United Nations
- WA	Water Security thrust

GLOSSARY OF TERMS

4th Industrial Revolution

The 4th Industrial Revolution refers to the social, political, cultural and economic shifts and upheavals resulting from the widespread availability of technologies based largely on the convergence of digital, biological, and physical innovations.

Adult basic education and training

The aim of adult basic education and training is to promote lifelong learning and personal development to enable adults to adapt successfully to the changing economic, social and political climate in South Africa.

Additive manufacturing

Additive manufacturing (also known as 3D printing) is defined as the use of different processes to physically replicate three-dimensional objects created by computer-aided design, through the joining of materials, usually layer by layer.

Artificial intelligence

Artificial intelligence is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, generalise, or learn from past experience.

Baseload generation

The generation of the baseload power, which refers to the minimum amount of electric power needed to be supplied to an electrical grid at any given time.

Big data

Big data means the high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing and enable enhanced insight, decision making, and process automation.

Term	Definition
Bio-identical	A bio-identical has the same molecular structure as a substance produced in the body.
Blockchain	Blockchain refers a digital database containing information (such as records of financial transactions) that can be simultaneously used and shared within a large decentralised, publicly accessible network. It is the technology at the heart of bitcoin and other cryptocurrencies. Blockchain technology is expected to disrupt several markets by ensuring trustworthy transactions without the necessity of a third party.
Carbon tax	A fee imposed by government on the burning of carbon-based fuels like coal, oil and gas. It is intended to help reduce and eventually eliminate the use of fossil fuels.
Circular economy	A circular economy is an alternative to a traditional linear economy (make, use, dispose), which sees resources kept in use for as long as possible, extracting the maximum value from them while they are in use, and then recovering and regenerating products and materials at the end of each service life. This includes the conversion of biological and non-biological waste into new resources and materials.
Data analytics	Data analytics refers to qualitative and quantitative techniques and processes used to enhance productivity and business gain. Data is extracted and categorised to identify and analyse behavioural data and patterns.
Decarbonisation	Decarbonisation refers to policies that will result in a reduction of carbon dioxide emissions by substituting lower-carbon sources of energy or taking equivalent actions such as reducing the consumption of goods and energy.
Early childhood development	Early childhood development (ECD) is a comprehensive approach to programmes and policies for children from birth to nine years of age with the active participation of their parents and caregivers. Its purpose is to protect the rights of children to develop their full cognitive, emotional, social and physical potential.

Greenhouse gas

A greenhouse gas is one that absorbs and emits radiant energy within the thermal infrared range. Greenhouse gases cause the greenhouse effect. The primary greenhouse gases in earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide and ozone.

Green economy

The green economy is an economy that aims to reduce environmental risks and ecological scarcities, thus ensuring sustainable development without degrading the environment.

Information and communication technology

Information and communication technology refers to unified communications and the integration of telecommunications (telephone lines and wireless signals) and computers, as well as enterprise software, middleware, storage and audio-visual systems, that enable users to access, store, transmit, and manipulate information.

Internet of Things

The Internet of Things is the growing network of physical objects that feature an Internet Protocol address for internet connectivity, and the communication that occurs between these objects and other Internet-enabled devices and systems.

Machine learning

Machine learning is the use of algorithms and statistical models by computer systems to perform a specific task without using explicit instructions, relying instead on patterns and inference. Machine learning is a subset of artificial intelligence.

Micro-grid

A small network of electricity users with a local source of supply that is usually attached to a centralised national grid but that can function independently.

Non-communicable disease

A non-communicable disease is one that is not transmissible directly from one person to another.

Off-grid

Not connected to or supplied with electricity, gas, water or sewage by publicly or privately managed utilities.

Term	Definition
Precision agriculture	The application of information technologies to provide, process and analyse multisource data of high spatial and temporal resolution for decision making and operations in the management of crop production. In respect of livestock, information technologies are used to assess fine-scale animal and physical resource variability in order to improve management strategies and optimise economical farming.
Precision medicine	A medical model that aims for the customisation of healthcare, with medical decisions, treatments, practices, or products being tailored to the individual patient. Diagnostic testing is used for selecting appropriate and optimal therapies based on a patient's genetic profile or other molecular or cellular analyses.
Square Kilometre Array	The Square Kilometre Array (SKA) project is an international effort, centred in South Africa, to build the world's largest radio telescope, which will have a collecting area of more than a square kilometre (one million square metres).
STI	Science, technology and innovation
STI domain	A broad but focused area related to STI, for example, an issue or set of issues, out of which one or more STI thrusts may be identified through the use of foresight tools. Some examples of STI domains are water use by agriculture, nutrition and human health, and smart technologies for improved transportation.
STI thrust	An STI thrust is an identified priority related to STI that could be relevant as input into the new STI decadal plan.
Sustainable Development Goal	The Sustainable Development Goals (SDGs) are set out in the 2030 Agenda for Sustainable Development, which was adopted by all United Nations Member States in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030.

Virtual reality

Virtual reality is the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside and/or gloves fitted with sensors.

Water-energy-food nexus

Water security, energy security and food security are linked to one another. Actions in any one particular area often can have effects in one or both of the other areas.

Zero-impact agriculture

Zero-impact farming refers to farming with the smallest possible impact on the environment.

EXECUTIVE SUMMARY

This report gives a condensed version of the South Africa Foresight Exercise for Science, Technology and Innovation (SAForSTI). The purpose of the exercise was to investigate the future of science, technology and innovation (STI) and the use of STI to improve the quality of life of all South Africans by addressing social and economic challenges in an inclusive and sustainable way. It is envisaged that the outputs of SAForSTI will inform and influence the identification and selection of priorities for the new decadal plan for STI.

To maximise the value of the outputs of SAForSTI for the new decadal plan, emphasis was placed on uncovering the potential of STI that could offer new impact in achieving the vision of the National Development Plan 2030 (NDP). While existing capabilities and capacities can produce new impact, new thinking is typically involved, and there was emphasis on the possibility of new impact being delivered by STI areas which are new to South Africa.

The following were borne in mind when the areas of STI on which to focus the foresight process were identified and analysed:

- Areas of STI that are currently robust and working effectively, and in which significant change is not anticipated.
- Areas of STI that appear to have a high potential for growth.
- Areas of STI that are relatively new in the context of the South African national system of innovation.

The SAForSTI process entailed the use of various methodologies informed by global experience and local context. The analysis process entailed the use of big data analytics. Broad stakeholder participation was a strong feature of SAForSTI.

In the end, SAForSTI identified the following nine STI domains (with their associated priorities or thrusts):

- The Circular Economy.
- Education for the Future.
- Sustainable Energy.
- The Future of Society.
- Health Innovation.
- High-tech Industrialisation.
- ICTs and Smart Systems.
- Nutrition Security.
- Water Security.

These domains are to be understood within the context of South Africa's current challenges related to inequality, poverty, unemployment, food security, health, education, water, climate and so forth. These societal challenges are systemic in nature; they require longer-term planning and policy actions across technological, economic and social structures and boundaries, and across national borders.

At the same time, South Africa is living in an age of hitherto unprecedented and spectacular advances in the techno-sciences, whose effects are beginning to permeate virtually every sphere of human and planetary life. This includes major advances in information and communications technology (ICT), biotechnology, nanotechnology, the Internet of Things (IoT), robotics, artificial intelligence (AI), machine learning, blockchain technology, and additive manufacturing, among many others.

All of these are elements of a new production revolution or fourth industrial revolution (4IR) that transforms production processes and products, markets, services and trading systems, entire industries and entire economies (NACI, 2019).

Countries have diverse views on the challenges and opportunities presented by the 4IR, depending on their current situation, level of development, objectives and STI interests. Some developed countries such as Germany, Italy, Japan and the United States of America have articulated and determined how they will seek to exploit the 4IR to meet local needs. South Africa, like other developing countries, must also determine ways to use the opportunities offered by the 4IR, while at the same time preparing to deal with unintended and negative consequences. A younger population can be a catalyst and a great advantage in the context of rapidly accelerating technological innovation and the socio-technological transformations associated with the 4IR.

SECTION I: GENERAL INTRODUCTION

CHAPTER 1

INTRODUCTION

FORESIGHT AS A PROACTIVE APPROACH TO THE FUTURE

"Foresight" is the umbrella term for innovative strategic planning, policy formulation and solution design methods that do not predict or forecast the future, but work with alternative futures.

Foresight has been defined as "a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilising joint action" (Miles and Keenan, 2002). So, typically, foresight (and when it is applied to issues of STI, ForSTI): (a) considers multiple futures, which may include possible, plausible and desirable futures; (b) is a participative process and (c) is action-oriented (Miles, Saritas and Sokolov, 2016).

Foresight for STI does not replace technological forecasting, technology assessment, future studies, or strategic research and development (R&D) planning. Each activity has its role and, while in many instances they can be mutually supportive, such activities are sometimes conducted in a fashion that closes off debate and considerably limits the scope of the alternative futures and paths of action that are considered (Miles, Saritas and Sokolov, 2016). It is important to differentiate between foresight and forecasting. As Miles, Saritas and Sokolov argue, "Forecasters often aspire for precision in an attempt to predict how the world might look at some point in the future, often using techniques like trend extrapolation, computer modelling, etc. By contrast, foresight does not seek to predict: instead, it is a process that seeks to create shared 'visions' of the future, appraisals that stakeholders are willing to endorse by the actions they choose to take today. It is focused on influencing the development of the future; some commentators portray this as creating the future. We are inclined to see 'creating' as too grand a claim, since many factors and actors play a role in this, and not all are mobilised in the Foresight process. Perhaps, we can best see ForSTI as helping to shape the future" (2016).

Foresight empowers decision makers and policy planners to use new ways of thinking and talking about the unfolding future, and implementing strategic plans that are compatible with such a future.

The premise of foresight is that the future is still in the making and can be actively influenced or shaped, rather than already decided by past thinking and actions, and therefore to be merely awaited and accepted.

This is an empowering realisation. Foresight allows the governments of developing countries to construct their own narratives of desired future, instead of relying on future foreseen by highly developed countries, which are not necessarily relevant to the contexts of other countries. Foresight enables public service organisations to frame future policy environments better and present decision-makers with more and better choices for inclusive growth and social justice. Participatory foresight frees countries from over-reliance on foreign or local technical experts, and invites citizens to contribute to discussions and decisions concerning their future.

Jennifer Gidley, in her ***The Future: A Very Short Introduction*** wrote, "For thousands of years we have struggled to predict, control, manage, and understand the future. Our forebears sought advice from oracles; read the stars through astrology; debated concepts of time and future philosophically; wrote utopias and dystopias; and, in the modern scientific era, tried to predict the future by accumulating and interpreting patterns from the past to extrapolate models of the future. But the single, predictable, fixed future that the trend modelling proposes does not actually exist. Instead, what is out there is a multitude of possible futures" (2017).

Foresight tries to steer a course between the unsettling uncertainty and unpredictability of the future and the need for data, information and intelligence to shape this future, without resorting to wishful thinking, prophecies, predictions or forecasts. Foresight is based on a range of skills: situational awareness of possible, probable and preferable futures; a proactive scanning of the horizon; an ability to sort, sift through and combine open, real-time and emerging data; and the creation of tight feedback loops. It entails the exploration of possible scenarios and pathways, the identification of future risks and opportunities, and the systematic rehearsal of potential responses.

The pressing imperatives of short-term priorities make it easy for today's decision-makers in both the public and private sectors to neglect longer-term challenges. Yet the limitations of the traditional projections of future trends using past data are raising awareness across the globe of the need to focus on medium to long-term time horizons as the context even for shorter-term responses.

Many decision-makers realise that foresight can identify opportunities and risks that would not otherwise have been considered. Foresight helps them to identify strategies that can handle a variety of outcomes. It can also help them to examine the unintended consequences of decision options, and to shape long-term actions.

In many countries, foresight has become a reasonably well-established part of public and private sector strategy, decision-making and advocacy. Being able to engage with the future sooner rather than later is recognised as essential. Hence the extensive use and institutionalisation of foresight capability by countries such as the USA, Finland, the United Kingdom, the European Union, South Korea, Japan, Nigeria and Russia, and organisations like the United Nations, the World Economic Forum and the Organisation for Economic Cooperation and Development (OECD), most multinational corporations and organisations, and civil society groupings interested in issues such as environmental or technology activism.

Foresight exercises vary in respect of approach, processes and output levels (national, regional and supranational). Where outputs are similar, there may be differences in respect of time horizons and an individual country's capacity to deploy new technologies.

While the SAForSTI learnt from the experiences of other countries, it had to adapt its approach to fit the local context. More information on this is provided in Chapter 2.

THE ROLE OF THE DEPARTMENT OF SCIENCE AND INNOVATION

The period 2014-2019 was characterised by critical reflection on the implementation of STI policy in South Africa and its role in shaping the future of South Africa. The Department of Science and Innovation (previously the Department of Science and Technology) carried out a number of initiatives, including the review of the 1996 White Paper on Science and Technology, a situational and performance analysis of the national system of innovation, and the first phase of the STI Institutional Landscape Review. A new White Paper on STI was developed and approved by Cabinet in March 2019. The objectives of the White Paper are as follows:

- Improved coherence and coordination.
- Increased partnering between business, academia, government and civil society in the national system of innovation (NSI).
- Strengthened and transformed NSI institutions.
- Increased human capabilities.
- Expanded research enterprise.
- Enhanced enabling environment for innovation.
- Improved funding across the NSI.

In pursuing these objectives, the aim is as follows:

- To ensure full alignment with the NDP objectives.
- To expand on successes and propose new approaches where necessary.
- To take advantage of opportunities presented by megatrends.
- To promote transformation.

The NDP, which identifies STI as critical for the creation of a competitive and sustainable economy and for addressing societal challenges such as education and health, advocates a strong, coordinated, coherent and effective STI system that promotes networks and partnerships between different actors in the public and private sectors, that contributes to transformation, and that recognises a multiplicity of knowledge production sites beyond higher education. It promotes the idea that knowledge should be shared as widely as possible across society, and it calls for the expansion of STI outputs by increasing government expenditure on R&D and encouraging increased expenditure by the private sector.

Building on previous successes and adopting new approaches where required, the White Paper on STI sets out a long-term policy approach for the South African government to ensure a growing role for STI in a more prosperous and inclusive society. It identifies inclusivity, transformation and partnerships as core themes, and proposes a range of actions to address policy coherence, the development of human capacity, knowledge expansion, innovation performance and increased investment.

In terms of the White Paper on STI, the role and functions of NACI are to be expanded to include monitoring and evaluation, coordination (through interministerial and Presidency-led mechanisms) and the strengthening of planning and agenda setting through the institutionalisation of foresight exercises. Future foresight exercises should build on and learn from previous efforts made since the adoption of the 1996 White Paper on Science and Technology.

Such efforts include the National Research and Technology Foresight exercises carried out in the 1990s, and SAForSTI, which give insight into possible futures for South Africa and priority options for the new STI decadal plan that will serve as an implementation instrument for the White Paper on STI.

SAForSTI sought to investigate the future use of STI to address societal, sustainability and economic challenges, create inclusive and sustainable growth, and improve quality of life and well-being in South Africa. The foresight exercise's specific tasks included the following:

- To identify local and global drivers or trends likely to have a major influence on STI and society in the next decades.
- To analyse the performance of the NSI in order to identify its weaknesses and strengths, and to characterise the current policy mix.
- To identify opportunities and competitive advantages in the NSI.
- To provide an understanding of what is being achieved and assess whether changes should be made.
- To make recommendations on the following:
    - Possible visions or futures, using a time horizon of 2030.
    - Key underlying principles.
    - Policy options for future priorities/grand challenges for the new decadal plan.

SAForSTI FOCUS AREAS

In order to carry out SAForSTI and provide the foresight exercise with a focus, nine STI-related priority areas, referred to as "STI domains", were identified through a prioritisation process involving wide consultation with stakeholders.

1. **The Circular Economy.** This is concerned with the generation of products that are restorative and regenerative by design, and which circulate through the economy repeatedly, thereby minimising waste. This includes the conversion of biological and non-biological waste into new resources and materials, as well as the restoration and protection of biodiversity.

2. **Education for the Future.** Education is the basis for a fair society and successful economy. By the 2030s, South Africa needs to be providing all its citizens with a quality of education that will enable them to find employment. One of the problems with the current public education system is the ineffectiveness of mathematics and science teaching and learning. All citizens, even those in rural areas, must have access to quality education. Technology offers an ever-growing range of opportunities to make such access possible. New and alternative learning technologies will not only give people basic education, but also equip them with the necessary skills for the future, while reducing social divides. Curricula should be developed to enable people to be more creative with skills for idea generation and problem solving.

3. **Sustainable Energy.** In the world today, energy is an integral part of all aspects of life. Although large cities in South Africa have a relatively stable energy supply, most rural and peri-urban communities have inadequate access to energy. These communities should be given opportunities to adopt new technologies to access clean and affordable energy from renewable sources (solar, wind and bioenergy). Sustainable energy technologies can leapfrog old technologies and their many limitations. Local sustainable energy production will reduce dependence on the national grid and create economic opportunities for the marginalised across South Africa. The energy domain focuses on clean, affordable and renewable energy solutions, energy efficiency and distributed generation.

4. **Future of Society.** STI for inclusive development needs to receive far more emphasis in any proposed STI interventions going forward than it has previously in the NSI. Listening to, understanding and responding to the collective and individual needs of people will be vitally important in harnessing STI to tackle societal challenges. Holistic and cross-cutting initiatives are required for the following reasons, among others:
   - To rebuild trust within the NSI – between the government, researchers, the private sector and the public.
   - To address the causes of unequal access to and participation in the STI value chain, thus ensuring sustainable benefits.
   - To create an engaged scholarship and recognition of the value of STI for social good.
   - To build a culture of research excellence that produces culturally acceptable technological solutions.
   - To establish a developmental and capable state that provides an enabling environment for STI development by all players within the NSI.
   - To ensure the self-sufficiency of communities through the adoption and adaption of technologies.
   - To drive self-initiated, lifelong learning as a cultural value.

5. **Health Innovation.** Overall, the healthcare system needs to be optimised in order to deliver better diagnostic and treatment services. Drug development is part of this. Prevention is cheaper than cure, and it is therefore important to educate society so that, where possible, people take control of their own health. It is also necessary to improve current health infrastructure and administration, which are inadequate, particularly in rural areas. As in other domains, mobile technologies, artificial intelligence and big data will bring enormous opportunities for the development of healthcare service delivery for all.

6. **High-tech Industrialisation.** Products, processes and services will be transformed through the application of smart and connected systems. The high-tech industry domain therefore focuses on the implementation of advanced manufacturing in South Africa using robotics, artificial intelligence, the Internet of Things and additive manufacturing, among others. This will transform old industries and give rise to new industries. Industry actors, including SMMEs, will need to equip themselves with the necessary skills, infrastructure and capacity for a successful transition.

7. **ICTs and Smart Systems.** ICTs are one of the key enablers of development in all domains, from agriculture to health, and from industry to service delivery and governance. There are a number of technologies under the umbrella of ICTs. As recognised in the 2016 OECD Science, Technology and Innovation Outlook, the Internet of Things promises a hyper-connected and ultra-digitally responsive society that supports human, societal and environmental development. Artificial intelligence offers unique opportunities to improve human lives and address major societal challenges.

Blockchain technology is expected to disrupt several markets by ensuring trustworthy transactions without the intermediation of a third party. All these technologies bring opportunities and threats for socio-economic systems. Their development therefore needs to be regulated by addressing concerns regarding security, privacy, equity and integrity.

8. **Nutrition Security.** Nutrition is essential for a healthy population. Malnutrition and stunting are currently serious issues in South Africa, with women and children particularly disadvantaged. Health and nutrition-related problems are generally caused by economic (low income, unemployment etc.) and environmental (climate change) factors. Technologies should be used to create opportunities for advancing farming in South Africa and making efficient use of arable land by reducing pressures resulting from climate change, waste and pollution. The nutrition security domain focuses on zero-impact agriculture and the application of biotechnologies, precision agriculture and big data.

9. **Water Security.** Water security as a basis for a thriving society and economy will depend on water and sanitation solutions that are responsive to new challenges and emerging needs and opportunities. Three aspects are key to water security: (a) water supply will need to be driven by an integrated mix of context-appropriate sources of water at the bulk, regional and local level; (b) the next generation of sanitation and wastewater (urban and industrial) solutions will need to be introduced, understood and then mainstreamed (low or no water toilets, energy and water-efficient technology, and smart waste solutions); and (c) water-sensitive designs for urban, peri-urban and rural spaces should be core to all water and sanitation planning and implementation (including grey water management, climate-resilient infrastructure, circular planning around water, and sanitation and wastewater flows).

   The 4IR is characterised by the intersection of physical, digital and biological spheres through technology. Cyberphysical systems have the potential to bring positive change in the management of water and sanitation resources and services. A water sector innovating around off-grid and decentralised solutions could, potentially, provide an opportunity in South Africa to (a) drive down service delivery costs; (b) allow for agility in responding to changing circumstances; (c) promote the proliferation of innovation-focused water-sector businesses; and (d) help to drive the industrial development of the water sector.

PURPOSE AND STRUCTURE OF THIS REPORT

This report provides an overview of the SAForSTI process and the main findings. Its intention is to unify the diverse strands into a coherent whole, to collate common themes and highlight divergences. It provides descriptions and analysis. It is necessarily only a selection of the documented outputs of SAForSTI, which the interested reader should refer to for detail.

A summative evaluation of the SAForSTI process itself will be commissioned in the near future. The impact evaluation of SAForSTI will take longer to finalise.

The synthesis report consists of three sections: The first section (Chapters 1 and 2) provides a general introduction and the rationale for using foresight, the approach taken to designing the exercise, the methodologies employed, and a description of the process followed.

The second section (Chapters 3 to 11) provides a description and elaboration of the results obtained for each of the nine STI-related areas (domains) for which possible futures were explored and for which options for future priorities were identified. These chapters have been written so that they can be read and understood on their own.

The third section (Chapter 12) provides a synthesis of the results from the nine different STI domains.

CHAPTER 2

APPROACH, METHODOLOGY, DESIGN AND IMPLEMENTATION

APPROACH ADOPTED

THE VISION OF THE NATIONAL DEVELOPMENT PLAN

A study of the situation and performance of the South African national system of innovation (NSI) (NACI, 2017) noted that the 1996 White Paper on Science and Technology set out a social contract that promoted scientific excellence and science and technology for all. The resulting policy mix was in fact largely focused on excellence by way of the National Research and Development Strategy and the Ten-Year Innovation Plan, assisted through various instruments which largely supported entities doing research based on their own interests, along with some directed research. Strong support was given to megascience projects for commercial and other reasons. However, the quest for science and technology for all did not receive adequate attention from the government, as evidenced in the reliance on donor funding for the realisation of the poverty reduction and alleviation goals of the National Research and Development Strategy and the Ten-Year Innovation Plan.

In light of the above, it was decided that SAForSTI should emphasise science and technology for all to offer options for rebalancing the policy mix in the formulation of the decadal plan. This decision was realised using the vision of the National Development Plan (NDP) as the overarching framework under which SAForSTI was conducted. As the NDP document had been published several years earlier, it was recognised that some of the details in the plan might be out of date. Thus, it was the vision of the plan and not its details that formed the overarching framework for SAForSTI. In practice this meant, for example, that SAForSTI was steered away from research with no obvious practical uses, and from the narrow interests of science and technology per se, and directed towards STI that could contribute towards achieving national priorities and the NDP vision of eliminating poverty, reducing inequality and increasing employment.

An example of a megascience project is the MeerKAT, a 64-dish radio telescope array, which is part of the Square Kilometre Array project.

NEW IMPACT FROM NEW THINKING

To maximise the value of the outputs of SAForSTI for the new decadal plan, emphasis was placed on uncovering the potential of STI that could offer new impact in respect of achieving the vision of the NDP. The following categories were borne in mind when identifying and analysing areas of STI on which to focus the foresight process:

- Areas of STI that are currently robust and working effectively, and for which significant change is not anticipated.
- Areas of STI that appear to have greater potential for growth.
- Areas of STI that are relatively new in the context of the South African NSI.

Areas of STI in the second and third categories were favoured because they hold the greatest potential for significant added value in the next 10 to 15 years.

BROAD STI STAKEHOLDER PARTICIPATION

The foresight exercise needed wide engagement with and participation by South African STI stakeholders from a diverse range of constituencies, such as research, higher education, the public sector, the private sector and civil society, to allow them the opportunity to help shape the exercise, and to secure stakeholder buy-in for the results of the process. A broad range of stakeholder participation was also necessary to ensure the quality of the process and its outputs. At the same time, the more narrowly focused participation of knowledgeable experts was required, so that they could provide their inputs concerning STI priorities for the future, based on solid expertise.

These considerations, including the tension between having broad and more narrowly focused participation, were considered when selecting and designing the methodology to be followed, as described in the section below.

INTERNATIONAL AND LOCAL COLLABORATING PARTNERS

A collaborative approach was taken to the design and implementation of the foresight exercise. Local implementing partners ensured that the exercise remained embedded in and relevant to the South African context. An international implementing partner could bring perspectives gained from experience with STI foresight in other contexts.

Non-Zero-Sum Development, a consultancy based in Pretoria, took the lead in implementing the foresight exercise, in close collaboration with the NACI Secretariat.

There was substantial collaboration with the Institute for Statistical Studies and the Economics of Knowledge (ISSEK), at the National Research University Higher School of Economics, in Moscow. ISSEK provided training to potential workshop participants in Foresight methodologies, and they assisted in the facilitation of the workshops that formed part of the foresight process. They also performed a bibliometric analysis of South Africa's research outputs, and semantic analyses of relevant documentation, the results of which were provided as inputs to the foresight process at several points.

The third collaborating partner was the Centre of Excellence in Scientometrics and Science, Technology and Innovation Policy (SciSTIP), based in Stellenbosch. They collected certain interview data on behalf of the foresight exercise, and also provided data pertaining to current research priorities for a wide range of sectors.

METHODOLOGY

Figure 1 depicts the overall process followed. The process benefited from multiple data and information-gathering methods, including desktop studies, big data analyses, online voting, higher-level stakeholder interviews, workshops and input from experts. Before the start of the workshops and online voting, a foresight training course was provided to selected stakeholders in order to foster a common view regarding a foresight process.

A major component of the process was based on an adapted type of scenario planning, and in order to give direction to the scenario planning, prioritisation criteria were formulated. These two aspects are elaborated below.

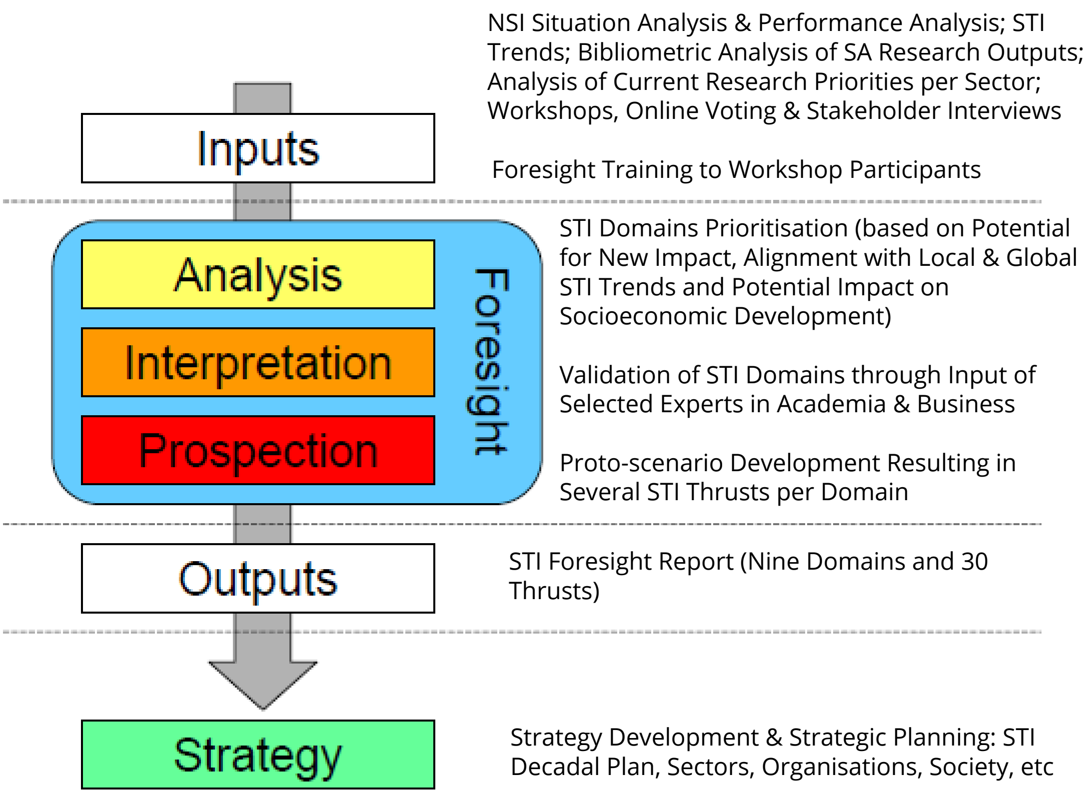

Figure 1: Summary of the STI foresight process used

SCENARIO PLANNING

SAForSTI made use of a modified version of scenario planning as the primary methodology followed.

A scenario is a story that relates how the present reality evolves into a state or condition set in the future (the time horizon). The story highlights decision points and external events, and the cause and effect linkages that lead to consequences of the decisions and external events. Usually the story is about a specific subject with a clear time horizon, e.g. "Innovation in South Africa in 2040".

A scenario contains a large amount of information about an envisaged future. The challenges and opportunities presented by the situations and environment in the story are intended to capture readers' imaginations and enhance their understanding. Usually, several scenarios are developed around a particular subject, so that alternative futures based on different key issues may be explored. It is difficult and time-consuming to draw up credible and useful scenarios.

A scenario may be considered useful, not because of the likelihood of its being realised, but because it is (a) plausible – presenting a rational route for the present to evolve into the depicted future, making decision points and causal processes explicit; (b) internally consistent – displaying consistency within the story, and across alternative scenarios; and (c) engaging – being sufficiently interesting to provoke the imagination and thus improve decisions made in the present.

Thus, a scenario is not a prediction or forecast of what will come to pass. It should not be seen as "probable", as the probability of every aspect of a particular scenario being realised is almost zero.

Scenarios are an effective means of presenting complex information to decision-makers and others in a way that is relatively easily absorbed, and making the future options seem realistic. A set of scenarios allows for different possibilities to be considered and the implications understood. They can therefore assist in the development of plans that are robust across a wide range of possible futures. However, such a set should not be understood to represent the only possible options, or thinking may be constrained.

The scenario-building method is valuable when there are a number of factors to be considered and the degree of uncertainty is high. The process stimulates strategic thinking, creativity, communication and organisational agility, and allows individuals and institutions to create their own future.

As indicated, a modified scenario-based methodology was followed for SAForSTI. The modification involved the production of proto-scenarios rather than full scenarios. A proto-scenario is a set of story fragments, not fully elaborated on, about a possible future related to a particular situation. A proto-scenario can fulfil a similar function to a full scenario, although in a more limited way, and can be produced far more quickly.

PRIORITISATION CRITERIA FOR DOMAINS AND THRUSTS

As indicated above, the overarching framework for SAForSTI was the vision of the NDP. In addition, it was noted that the intention was to steer SAForSTI to focus on areas that were likely to produce thrusts that had the maximum potential for new impact.

While remaining aligned with the vision of the NDP, it was also important to harness the potential of the current trends in STI, both globally and locally. Advances in science and technology, and related innovations, have the potential to deliver significant benefit, in line with national priorities.

These three considerations (the vision of the NDP, new impact and STI trends) were the overarching criteria for selecting the top-priority STI domains and thrusts. Figure 2 depicts these criteria and their inter-relationships.

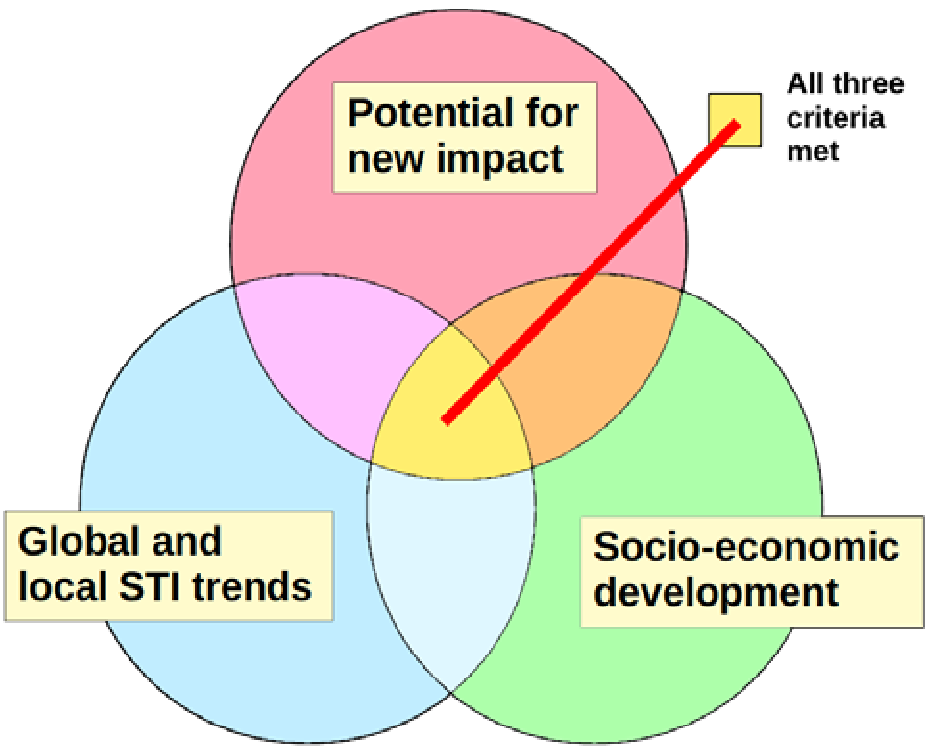

FIGURE 2: SELECTION CRITERIA FOR THE FOCUS OF SAForSTI

THE SAForSTI PROCESS

Overview

In summary, SAForSTI consisted of three phases.

1. During the preparation and initiation phase, several desk studies were undertaken, which served as inputs for the next phase. In addition, planning and preparation took place to facilitate the implementation of the remainder of the project.

2. During the STI domain identification and selection phase, the top-priority STI domains were identified, using workshops and online processes.

3. The STI thrust identification and prioritisation phase was centred on two stakeholder workshops, during which possible futures in each domain were envisaged, and related proto-scenarios were developed. The output of the phase was the set of proposals for STI thrusts.

Phases 2 and 3 both included interviews with a range of STI stakeholders to obtain input for the identification of domains and thrusts. Big data analysis also straddled phases 2 and 3. This involved bibliometric analyses of the scientific outputs of South Africa, and semantic analyses of large document sets to identify emerging and evolving STI-related trends.

About 17 months were required for the activities associated with these phases.

PREPARATION AND INITIATION

The preparation and initiation phase consisted broadly of the following steps:

- A survey was undertaken of global and local STI trends by ISSEK and Non-Zero-Sum Development (see Annexure A).

- Several studies were commissioned to provide input for SAForSTI, among other purposes, and to assist in the process of formulating the new STI decadal plan. These studies resulted in the following reports:
    - Situational Analysis: Innovation Theory, Practice and South African Context (2016).
    - Synthesis Report: Review of the White Paper on Science and Technology and High-Level Framing for a New Decadal Plan (2016).
    - Towards the Next-generation Science and Technology White Paper for South Africa: Innovation for Transformative Change and Inclusive Development: Situational Analysis (2017)
    - Towards a Next-Generation Science, Technology and Innovation White Paper for South Africa: Performance Analysis (2017).
- Awareness was raised among STI stakeholders (both key stakeholders and general stakeholders) about SAForSTI. This was achieved through email and social media campaigns, and promotional videos. There was engagement with other STI-related institutions that agreed to send information about the exercise to the people on their mailing lists. In this way a large number and wide range of stakeholders was reached.

- ISSEK conducted a two-day training course in foresight concepts and methodologies for STI stakeholders, drawn primarily from the public and higher-education sectors, who were expected to participate in SAForSTI.

Discussions were held with SciSTIP to identify possible areas of collaboration between SciSTIP and SAForSTI. At the time of the foresight exercise, SciSTIP was preparing to conduct interviews with a wide range of NSI practitioners as part of a study. It was agreed that SciSTIP would include a question supplied by SAForSTI in its interviews, and the outputs of the interviews would then be provided to SAForSTI. It was also agreed that, based on its study, SciSTIP would provide profiles of several sectors relevant to SAForSTI (including energy, agriculture, water, environment and human settlements, mining and minerals, and manufacturing) as they became available.

STI DOMAIN IDENTIFICATION AND SELECTION

This phase identified possible STI domains, and then selected those considered to be of the highest priority. The selected STI domains were to be used as focus areas for the next phase of SAForSTI, during which possible futures would be envisaged for each of the selected domains, and subsequently priority initiatives (STI thrusts).

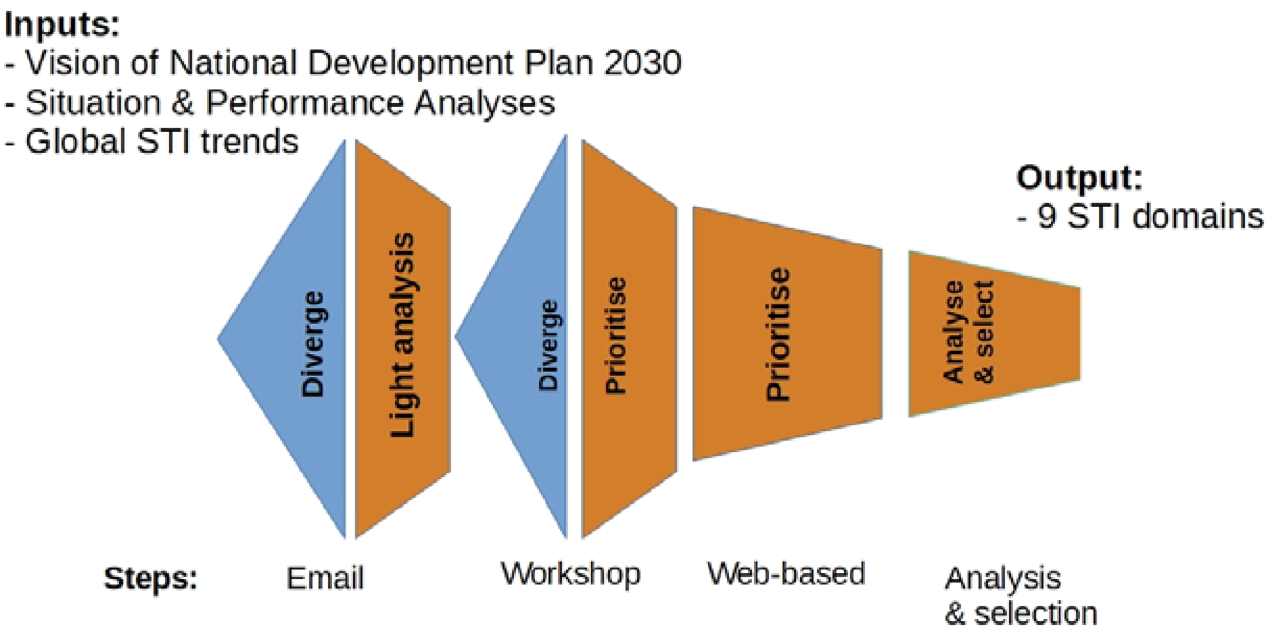

Figure 3: STI domain identification and selection process

Figure 3 depicts the STI domain identification and selection process. The process consisted of four high-level steps:

- STI stakeholders were invited to propose STI domains via email.
- The consolidated list of proposed domains then served as input for a two-day stakeholder workshop at which domains were considered, and some other domains identified. To achieve broad-based participation, workshop attendees were invited from a wide range of sectors and from most provinces.
- The resulting list of possible STI domains was then published on the project website and all stakeholders were invited to vote the domains they considered their highest priority.
- The results were analysed and then, using the outputs
- of all three steps above, the NACI Council selected the top priority domains.

This multi-stage selection process is also depicted in Figure 4.

At a more detailed level, this process involved the following:

- All stakeholders were invited to propose STI domains via email, using templates that were supplied. Invitations to do so were disseminated through multiple email mailing lists, partner organisations and via social media platforms. Eighty STI domains were proposed (Annexure B).
- The STI domains proposed were used as input for a two-day STI stakeholder workshop held in Pretoria. Invitations to the workshop were sent to a wide range of stakeholders to ensure, as far as possible, good representation across a broad range of sectors, interests and provinces. About 50 stakeholders participated in the first workshop.
- During the workshop, participants brainstormed possible areas and issues related to STI, and then prioritised them.
- The workshop participants identified and prioritised 45 possible STI domains (Annexure C). These were analysed with the initial 80 domains. There was overlap, to a greater or lesser extent, between many of these domains. The domains were therefore consolidated into a list of 31 possible STI domains (Annexure D).
- This list was posted on the foresight project website and all stakeholders were invited to prioritise them through a voting process. In order to vote, stakeholders had to have registered on the website with their name and contact details. Votes were received from 210 stakeholders.
- The results of the voting were analysed. This produced a shortlist of 13 STI domains (Annexure E).
- The NACI Council was then presented with all of the above information, including the various lists of proposed STI domains, to make a final selection of domains.

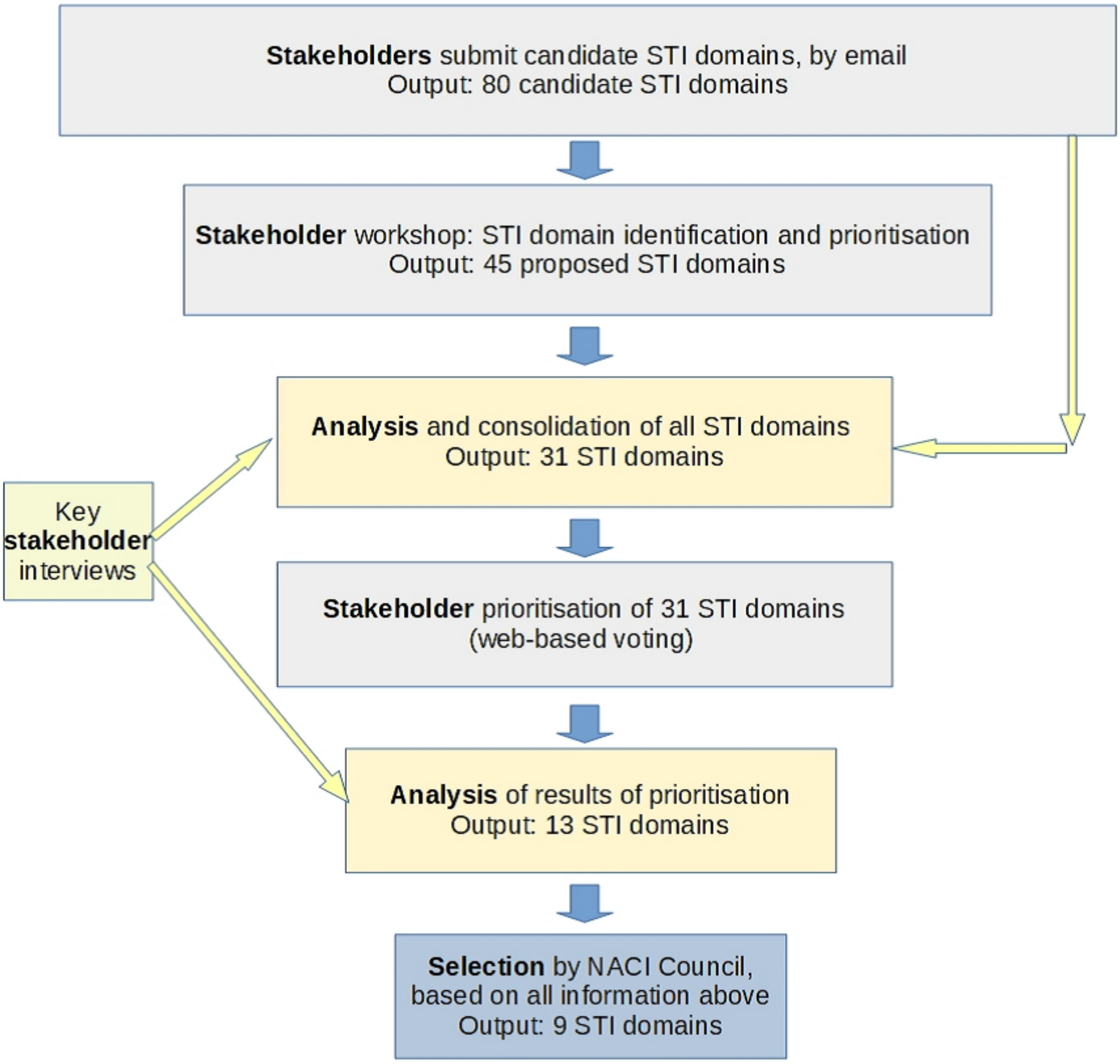

Figure 4: The STI domain identification and selection process

The Council selected the following nine domains:

- The Circular Economy.
- Education for the Future.
- Sustainable Energy.
- Future of Society.
- Health Innovation.
- High-tech Industrialisation.
- ICTs and Smart Systems.
- Nutrition Security.
- Water Security.

STI THRUST IDENTIFICATION AND PRIORITISATION

The purpose of the STI thrust identification phase was to explore possible futures associated with each of the selected STI domains, using a 2030 time horizon, identify preferred futures, and then identify and elaborate priority initiatives with a view to realising aspects of the preferred futures. Initially, eight domains were selected (the Future for Society domain was later added). Figure 5 depicts the process that was followed to identify and then describe STI thrusts.

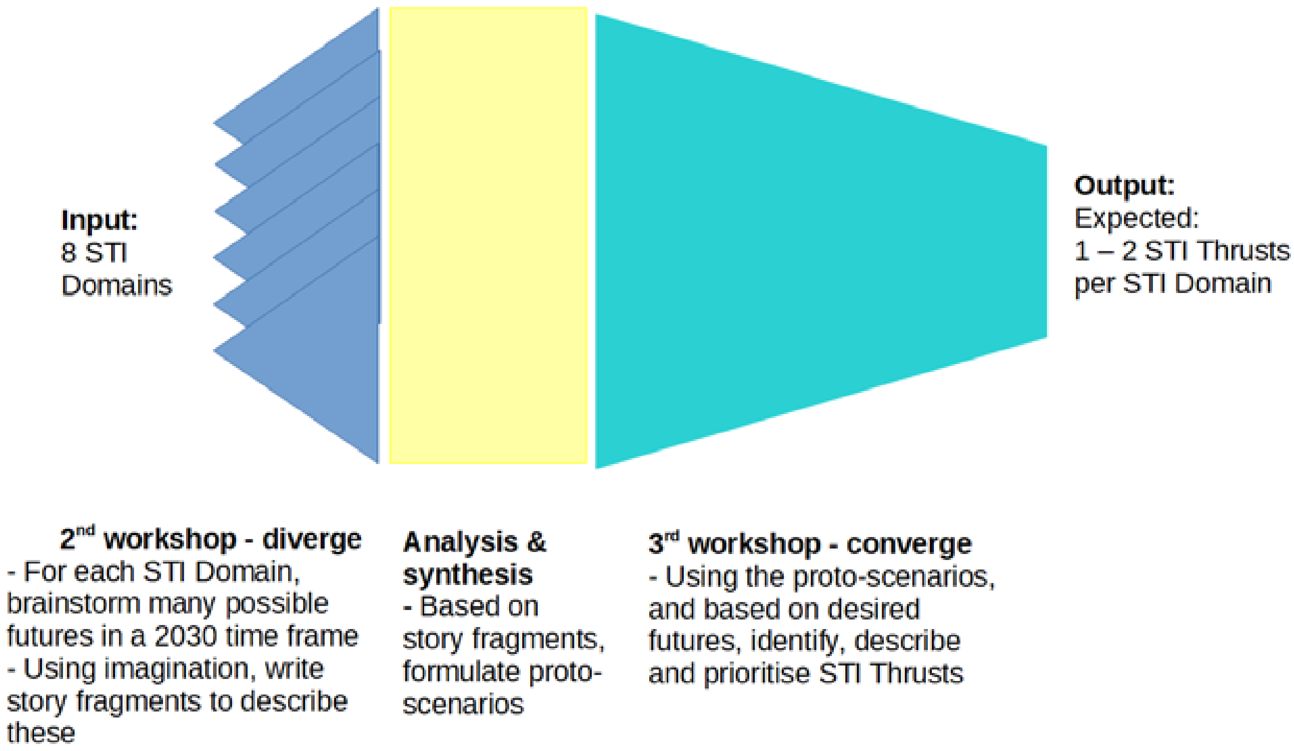

Figure 5: The STI thrust identification and prioritisation process

The process consisted of the following steps:

- A two-day workshop was held (the second foresight workshop). For this workshop, participants were invited on the basis of their expert knowledge in one or other of the STI domains initially selected. Eight working groups were formed for the workshop, one for each of the eight STI domains to be explored (the Future for Society domain had not been added at this stage). Some participants were also invited on the basis of their cross-cutting knowledge and expertise, to ensure that linkages between STI domains, and between any resulting STI thrusts, could be properly addressed. About 45 expert stakeholders attended the second workshop.
- Expanded descriptions of the selected STI domains, and between any resulting STI thrusts, could be properly addressed. About 45 expert stakeholders attended the second workshop.
- Expanded descriptions of the selected STI domains, along with key related issues, were provided to the workshop participants as inputs for the process. In describing the STI domains, the need to uncover new impact through the foresight process was emphasised. This shaped the way the domains were described, which in turn shaped the thrusts identified.
- The results of a semantic analysis undertaken by ISSEK of a wide range of relevant documents, and semantic maps, identifying key topics and trends for each of the STI domains, were also used as input for the workshop.
- During the second workshop, each working group first brainstormed and envisioned different possible futures associated with their domain. Divergent and out-of-the-box thinking was encouraged. Participants then wrote story fragments to describe the main aspects of the different futures they imagined.
- Following the workshop, the story fragments were analysed and then synthesised by the foresight facilitators into three proto-scenarios for each STI domain working group. These proto-scenarios served as inputs into the third workshop.
- The third two-day workshop was held with largely the same participants as the second workshop. In some cases, those who participated in the second workshop were not available for the third, and so new experts were invited to fill their places. For some of the working groups, gaps in the group's expertise profile had been identified, and in these cases, additional experts were also invited to fill the gaps.
- During the third workshop, the working groups first identified the aspects of the proto-scenarios that represented desired futures, and then identified possible STI thrusts that might contribute towards achieving those futures. The aim was to reach consensus on a few priorities.
- The identified STI thrusts were then prioritised, and the highest priority thrusts were elaborated in more detail, in the form of outlines of STI thrust proposals, using a template provided. (See Annexure F for thrust proposal outlines.)

- The thrusts were assessed in terms of their socio-economic impact, particularly new impact, and strategic value. The feasibility criteria included (a) the availability of required knowledge and expertise; (b) the availability of institutional capacity; (c) the availability of infrastructure; (d) the policy and regulatory environment in place; (e) social and ethical acceptability; (f) the amount of relevant funding currently allocated; and (g) the ease with which barriers and obstacles could be addressed.

Following the production of the STI thrust proposal outlines, ISSEK undertook a more focused big data analysis using its database of documents to produce more detailed and relevant outputs for each of the STI domains and their associated thrusts.

STAKEHOLDER INTERVIEWS

During the STI domain and thrust identification phases, interviews were conducted with key STI stakeholders to gain their views concerning priority STI domains, and also concerning key issues for SAForSTI as a whole. In general, stakeholders who were unlikely to participate in the workshops were issued invitations for interviews. Most of the interviews were conducted face-to-face, but three were done by telephone. Table 1 indicates the interviews undertaken, by sector.

Table 1: Stakeholder interviews

SECTOR	POSITION	NUMBER OF PEOPLE INTERVIEWED
Higher education	Deputy vice chancellor/former VC	3
Science council/project	CEO	2
Private sector (SMME)	CEO	2
Public sector	Former DG, Chief Director	2
Other	Various	2

In addition to these interviews with key stakeholders, input was also obtained from interviews conducted by SciSTIP. The focus of the SciSTIP interviews was of direct relevance to SAForSTI, and a question from SAForSTI concerning the perceived 10-year priorities for STI was added to the interview questions. An early version of a report summarising the outputs from the SciSTIP interviews was provided to SAForSTI (Annexure G).

The inputs and insights provided by the key interviewees, and also those from the SciSTIP interviews, were analysed to distil the primary messages for SAForSTI. The results of this analysis shaped the materials that were provided as inputs to the participants in the workshops. In particular, the report of the SciSTIP interviews was provided as an input to participants at the first workshop. The results of all the interviews also shaped the further analyses undertaken during the foresight process.

BIG DATA ANALYSIS

Big data analysis was undertaken by ISSEK. Providing a new evidence base, big data analyses make valuable contributions to foresight exercises. The types of analyses involved in this phase were the following:

1. Bibliometric analysis of the scientific outputs produced by South Africa. The bibliometric analysis helped with understanding South Africa's competences in research in relation to the STI domains, scientific capacity within the country, and key collaborators across the world and in Africa. The temporal analysis of scientific outputs indicates the mature and emerging areas in the South African research landscape.

2. Semantic analysis of large document sets was undertaken using the "iFORA (a proprietary intelligent foresight analytics system developed by ISSEK). The system uses advanced semantic analysis, machine learning and AI algorithms to integrate information from diverse sources, including scientific articles, patents, news, grants, and analytical reports, among other things, with the aim of generating new knowledge on emerging and evolving trends. The intelligent foresight analytics system generated semantic maps for the domains and thrusts identified in SAForSTI. Detailed analyses of maps were provided to describe emerging issues and topics in each domain and its associated thrusts.

The results of the big data analyses may be found in Annexure H.

CHALLENGES AND LIMITATIONS

During an undertaking such as the present foresight exercise, there are inevitably challenges and limitations, whether foreseen or not, that must be addressed as far as possible, and any weaknesses mitigated against where feasible. Some of these are discussed below.

- The time horizon specified for the scenarios to be envisioned through SAForSTI, namely 2025-2030, fitted with the time frame of the end point of the new decadal plan. It also coincided with the time frame of the National Development Plan.

  However, the year 2030 is only 11 years into the future, which in a foresight context is at the short end of typical scenario time horizons, which usually range from 10 to 30 years (although sometimes they are longer).

  Bearing in mind that scenarios must describe plausible futures, using a closer time horizon generally results in scenarios that show greater continuity with the present. This means that unexpected, surprising and highly visionary outputs are less likely. A more distant time horizon allows for greater discontinuity with the present, with space to envision possibilities that might be considered far-fetched.

  In order to mitigate against this limitation, the initial envisioning (creativity or "dreaming") process during the second workshop was centred on a 2040 time-horizon, and then later, during the development of proto-scenarios, the time horizon was brought forward to 2030. Nevertheless, the outputs of SAForSTI, while driving towards plausible but not necessarily likely futures in 2030, generally show strong continuity with the present and the issues that currently face South Africa.

  If a time horizon of 2040 or 2050 had been used for SAForSTI, the STI thrusts that emerged might have been more farsighted and visionary.

- A wide range of STI stakeholders from many sectors and other categories participated in the different phases of SAForSTI (e.g. from higher education, research, the public sector, the private sector and NGOs). Nevertheless, the strength of participation varied between sectors and other categories. In particular, it was a challenge to secure strong participation by the private sector in the exercise, during both the online process and the workshops. However, valuable contributions were made by stakeholders from the private sector in both the domain and thrust identification processes.

In addition, special efforts were made to engage more fully with the private sector, and with other stakeholders from whom input would otherwise not have been received. This was the focus of the one-on-one interviews conducted with key stakeholders. While this effort achieved its objective in a significant way, and important inputs were made by private sector stakeholders in particular, many requests for interviews were declined.

- For many, participating in a foresight exercise is a new experience, which requires new skills and a major shift in mindset. This can take time to develop and the gap was particularly evident during the stakeholder workshops. For example, it often took participants some time to shift into a future-oriented mode of thinking. Developing a culture of using foresight for strategic and related planning in South Africa, and especially among STI stakeholders, would facilitate more advanced and effective levels of participation in future exercises.

CONCLUSION

A total of 30 thrusts were identified, each associated with one of the nine STI domains. They are as follows:

1. CIRCULAR ECONOMY

CE1: Reducing, Reusing and Recycling Waste.
CE2: Ensuring Sustainable Water, Energy and Food (Agriculture) Security.
CE3: Low-Carbon and Climate-Resilient Economy.
CE4: Smart Connectivity and Mobility in Communities.

2. EDUCATION FOR THE FUTURE

ED1: Skills for the 4th Industrial Revolution.
ED2: Inclusive Innovation and Development.
ED3: Curriculum Development 2030.

3. SUSTAINABLE ENERGY

EN1: Clean, Affordable and Sustainable Energy for All.
EN2: Renewable Energy Sources and Technologies.
EN3: Energy Efficiency Solutions for Industry and Household Use.
EN4: Distributed Energy Generation and Storage.

4. FUTURE OF SOCIETY

FS1: Policies and Indicators for STI in a Changing South African Society.
FS2: STI for Inclusive, People-Led Development.

5. HEALTH INNOVATION

HE1: Optimisation of Health Systems.
HE2: Improving the Quality of Healthcare.
HE3: Digitisation of Health Systems.

6. HIGH-TECH INDUSTRIALISATION

HT1: Enabling Small Business to Adopt High Tech.
HT2: Was incorporated into the domain Education for the Future.
HT3: New Thinking for New Industries.
HT4: New Thinking for Old Industries.

7. ICTs AND SMART SYSTEMS

IT1: Checks and Balances for a Digital Future.
IT2: ICT Infrastructure and Internet Access.
IT3: Big Data, Data Analytics and Decision Support.
IT4: Smart and Sustainable Municipal Service Delivery.

8. NUTRITION SECURITY

NU1: Zero-impact Agriculture.
NU2: Use and Acceptance of Modern Biotechnology.
NU3: Personalised Information for Healthy Nutrition for All.
NU4: Precision and Big Data in Agri-businesses.

9. WATER SECURITY

WA1: Future-oriented Water and Sanitation Solutions.
WA2: Embedding the Water Sector in 4IR.
WA3: Off-grid and Decentralised Water, Wastewater and Sanitation Solutions.

SECTION II: IDENTIFIED STI DOMAINS

CHAPTER 3

THE CIRCULAR ECONOMY

INTRODUCTION

OVERVIEW

South Africa's economy is currently based on a traditional, linear production model (make, use, dispose). A circular economy sees resources kept in use for as long as possible, extracting the maximum value from them while they are in use, and then recovering and regenerating products and materials at the end of each service life. This includes the conversion of biological and non-biological waste into new resources and materials. In a circular economy, waste products that would usually be disposed of in the linear model are instead recycled and remanufactured, thus dramatically reducing the amount of waste material that requires disposal. The Circular Economy domain is therefore concerned with the generation of products that are restorative and regenerative by design, and that circulate through the economy repeatedly, thereby minimising waste. This includes the conversion of biological and non-biological waste into new resources and materials, as well as the restoration and protection of biodiversity.

ISSUES AND DRIVERS

During stakeholder interviews, the circular economy was identified as poorly understood by those participating in South Africa's economy, in all sectors and at various levels of participation. However, it is seen as a potentially powerful opportunity (and unavoidable requirement) with unbounded scope for research and innovation. South Africa faces several challenges as it moves towards a functional circular economy. Virgin materials are often cheaper than recycled materials. Although the volumes of recyclable material generated in South Africa are relatively small, an increase in the production of disposable goods is expected over the next two decades. In this context, the challenge of making the recycling of materials economically viable will need to be addressed. Designing consumer products in such a way to ensure that they remain within a circular economy, rather than being disposed of, is critical to the achievement of the Sustainable Development Goals in the United Nations 2030 Agenda for Sustainable Development, to which South Africa is a signatory. In addition, the circular economy is an emerging sector that will provide significant employment opportunities in the future.

South Africa is one of only a few megadiverse (extremely biodiverse) countries globally and the country's unique climate and geographical features enable it to support ecosystems and a unique blend of biodiversity. Support for a circular economy is a necessity for the country if this natural advantage is to be protected, valued and leveraged for inclusive growth through ecologically smart innovations.

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 6 depicts the contribution by South African researchers to the global process of knowledge generation related to the circular economy during the period 2008 to 2018, based on data from the Scopus abstract and citation database. It is evident that there is a growing scientific emphasis on the circular economy among South African researchers.

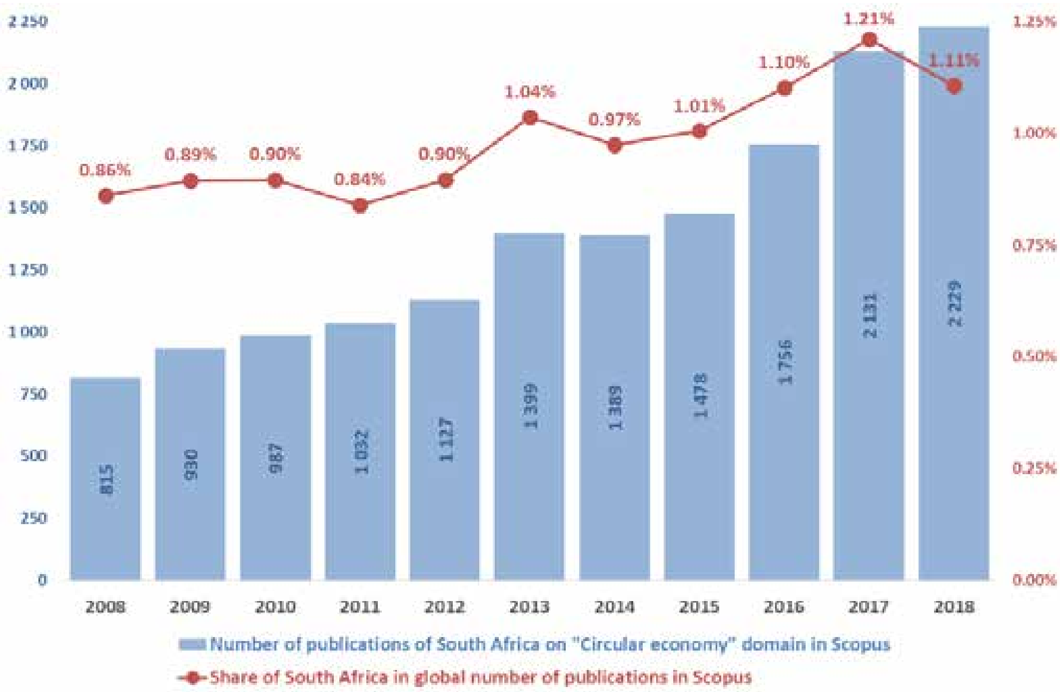

Figure 6: Publication activity related to the Circular Economy domain

Figure 7 depicts publication activity during the period 2008 to 2018, relative to other countries.

The number of publications produced has been normalised using both GDP and population size. Of the BRICS countries (highlighted), South Africa produced the highest number of publications related to the Circular Economy, per GDP and per size of population.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Portugal	18.6	219.3	84.8
Malaysia	21.2	314.7	67.4
Iran	28.8	454.0	63.4
Finland	15.5	252.3	61.4
Poland	29.1	526.5	55.3
Denmark	17.4	329.9	52.7
Sweden	27.4	535.6	51.2
Australia	66.6	1323.4	50.3
Norway	17.7	399.5	44.3
South Africa	15.3	348.9	43.9
Spain	57.6	1314.3	43.8
Netherlands	36.0	830.6	43.3
Canada	70.7	1647.1	42.9
UK	102.1	2637.9	38.7
Switzerland	25.0	679.0	36.8
Belgium	18.1	494.8	36.6
Austria	14.4	416.8	34.5
India	81.9	2650.7	30.9
Italy	56.0	1943.8	28.8
Turkey	22.3	851.5	26.2
France	58.9	2582.5	22.8
South Korea	34.8	1530.8	22.7
Germany	83.7	3693.2	22.7
China	270.5	12237.7	22.1
Brazil	42.5	2053.6	20.7
Russia	27.7	1578.4	17.5
US	340.0	19485.4	17.4
Mexico	16.4	1150.9	14.2
Japan	51.7	4872.4	10.6

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Norway	17.7	5.3	334.0
Denmark	17.4	5.8	300.0
Switzerland	25.0	8.5	294.1
Finland	15.5	5.5	281.4
Sweden	27.4	10.1	271.3
Australia	66.6	24.6	270.7
Netherlands	36.0	17.1	210.5
Canada	70.7	36.7	192.6
Portugal	18.6	10.3	180.6
Austria	14.4	8.8	163.7
Belgium	18.1	11.4	158.8
UK	102.1	66.0	154.7
Spain	57.6	46.6	123.6
US	340.0	325.1	104.6
Germany	83.7	82.7	101.2
Italy	56.0	60.5	92.6
France	58.9	67.1	87.8
Poland	29.1	38.0	76.6
South Korea	34.8	51.5	67.6
Malaysia	21.2	31.6	67.0
Japan	51.7	126.8	40.8
Iran	28.8	81.2	35.5
Turkey	22.3	80.7	27.6
South Africa	15.3	56.7	27.0
Brazil	42.5	209.3	20.3
China	270.5	1386.4	19.5
Russia	27.7	144.5	19.2
Mexico	16.4	129.2	12.7
India	81.9	1339.2	6.1

Population (2017)

Figure 7: Number of publications relevant to the Circular Economy domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 8 depicts the quality of publications in the primary areas of specialisation relevant to the Circular Economy domain.[2] The size of each bubble indicates the number of articles published from 2011 to 2015 in the given area of specialisation.

Relevant areas requiring additional investment to build research capacity include Engineering, Materials Science, Decision Sciences, Mathematics, and Computer Science.

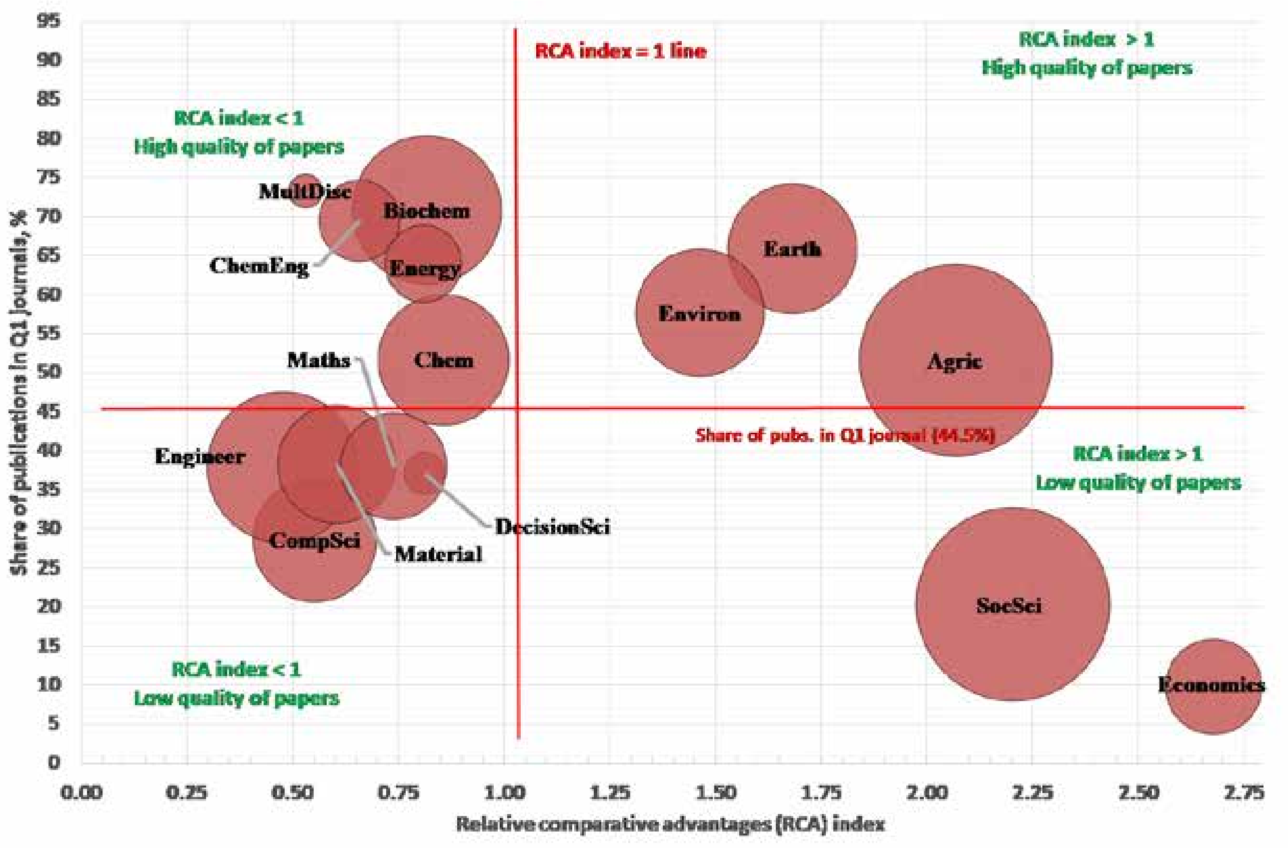

Figure 8: Quality of publications relevant to the Circular Economy domain

[2] The revealed comparative advantage (RCA) index measures the degree of scientific specialisation of a country in a given subject area. An RCA index value of greater than one indicates an area of research specialisation. The quality of publications may be assessed by determining the proportion published in first quartile journals using the SJR (SCImago Journal & Country Rank) citation index. For the key to the areas of specialisation, see Annexure I.

RECOMMENDATIONS

Four priority areas (STI thrusts) have been identified for the Circular Economy domain. Summary descriptions of these are set out below, with more detailed descriptions presented in Annexure F.

CE1: REDUCING, REUSING AND RECYCLING WASTE

This thrust addresses the development and deployment of performance improvements in waste management (e.g. mining, agriculture/food production, human waste and electronic waste), with the intention of building and strengthening a sustainable, regional, secondary-resources economy in South Africa. The maximised diversion of waste from landfills towards value-adding opportunities will create significant and broad social, economic and environmental benefits. The result will be a serviceable waste logistics system with effective resource recovery, based on appropriate technology solutions, improved decision-making and planning via robust modelling and analytics, strengthened RDI capability and capacity, and the potential to export knowledge and know-how.

The implementation of the Waste Research, Development and Innovation (RDI) Roadmap will be the first step required, underpinned by the development and approval of appropriate policy and strategy aligned with waste-related planning and RDI. Investment is needed in training and skills development; the establishment of facilities for waste recycling, including collection points; developing technologies for the treatment of waste; and providing funding to support these interventions. A strong monitoring and evaluation system will be required to track policy implementation. This may be fairly difficult to implement. The greatest challenge, however, will be to gain societal and industry buy-in for moving towards a circular economy.

CE2: ENSURING SUSTAINABLE WATER, ENERGY AND FOOD (AGRICULTURE) SECURITY

The water-energy-food nexus is gaining recognition nationally, regionally and internationally as a cross-sectoral approach to resource management and sustainable development. This thrust addresses the need to pay more attention to the water-energy-food nexus in South Africa, as this forms the basis of a self-sufficient economy. Climate change will have serious implications for the nexus, with changes in one area affecting one or both of the other areas. Thus, a crisis in any of the three areas would have wide-ranging consequences for the entire country.

This thrust will require a shift towards a more integrated, cross-sectoral governance, planning and management paradigm, and an intersectoral business model for collaboration that includes, for example, waste reuse and targeted resource recovery technologies; alternative sources of water, including water reuse and innovative infrastructure and efficiency solutions; renewable energy and innovative storage solutions; and precision farming and drought resistant crops in agriculture.

The outcome of addressing this thrust will be increased (a) water security, with access to safe drinking water and sanitation and the responsible use of water, through reuse and recycling; (b) energy security through access to clean, uninterrupted, reliable and affordable (renewable) energy; and (c) food security through the availability of and access to sufficient, safe and nutritious food to meet the dietary needs of all South Africans. The interdependence between the nexus elements is complex and will require new ways of thinking, new materials, new data sources and a new understanding of how to make it work.

CE3: LOW-CARBON AND CLIMATE-RESILIENT ECONOMY

This cross-cutting thrust focuses on decarbonising the economy to improve environmental sustainability. This must be achieved within and between the other Circular Economy thrusts. It addresses the need to find alternatives to the country's heavy dependence on fossil fuels and the current unsustainable greenhouse gas emissions.

The thrust recommends the setting of targets to (a) reduce carbon emissions across the country; (b) increase urban and rural forest cover, with no threat to biodiversity; and (c) provide for the identification and restoration of critical urban and rural ecological infrastructure.

The outcomes of this thrust will be more stable and moderate weather conditions/events; improved resilience to natural disasters by marginalised communities; the stabilisation of the impacts of floods, droughts and fires; and increased biodiversity resulting in healthier urban and rural ecosystems. The reduction in air and water pollution will have broad positive health impacts, particularly for poor and marginalised communities.

CE4: SMART CONNECTIVITY (HUMAN-MACHINE INTERFACE) AND MOBILITY IN COMMUNITIES

This thrust addresses the need for communities, utilities, industry and businesses to use the Internet of Things (IoT) to connect in new ways to a wide range of resources. The IoT could open up trade and exchange for circular economy goods/services, support better-informed forecasting, planning and monitoring in, for example, agriculture, health and education. The IoT could also streamline production-related and consumption-related transport options. Marginalised communities currently lack the skills and information to enhance their lives, are unable to use resources efficiently, and are directly affected by weakly coordinated intra and intersectoral transport and logistics links.

The outcomes of this thrust are (a) smart ICT and transport systems; (b) SMMEs in rural and marginalised communities who can deliver circular economy goods and services around ICT; (c) more households driving circular economy businesses in urban and peri-urban areas; (d) reskilled communities and behavioural shifts as a result of access to smarter systems and new virtual education options; and (e) a reduction in bureaucracy and smarter government services around access and livelihoods for health, food, water, energy, transport and waste.

Implementation could involve the initiation, through strategic partnerships, of strategic pilot sites in rural, peri-urban and urban spaces, to demonstrate options and scale-up opportunities on a broader scale. This will require political buy-in to kickstart the process, with the establishment of a coordination and implementation unit under the leadership of a designated government department.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

While many countries are taking active steps towards growing a circular economy, the concept and its implementation represent a new trajectory for South Africa. An innovative, transdisciplinary, STI-based, holistic waste strategy is needed to reduce costs, create jobs and micro-industries, and benefit the economy, the health of people and the environment, and maintaining the country's biodiversity.

The bibliometric analysis indicated that South Africa already has significant and relevant research capacity that can be deployed to address challenges related to the circular economy. This is especially the case in the areas of agricultural and biological sciences, environmental science, and earth sciences. Funding for research in these areas should be maintained. There are a number of relevant areas requiring additional investment to enhance research capacity. Some of these are engineering, materials science, chemistry, chemical engineering, biochemistry, genetics and molecular biology, energy, and the social sciences.

By following a trajectory towards implementing the first stages of a circular economy, South Africa can improve its position with respect to achieving the Sustainable Development Goals. As a productive circular economy emerges, new employment opportunities may be expected to become available.

Some specific policy considerations are as follows:

- Formulate and implement platforms and instruments to ensure much higher levels of collaboration between relevant government departments, science councils, academia and industry. For example, a roadmap for the circular economy should be developed, involving stakeholders and experts from the water, energy and agriculture sectors, including government, civil society, research, and the private sector. The roadmap development process should address all the nexus-related issues, e.g. for energy-food, biofuels, energy for fertilizers, food supply chain, transport.
- Ensure that there is synergy between the policy and strategy of the Department of Environment, Forestry and Fisheries on the one hand, and waste-related planning, research, development and innovation on the other.
- All strategic plans of government departments and state-owned enterprises should include a climate change component. Industry should be encouraged to follow a similar course.

CHAPTER 4

EDUCATION FOR THE FUTURE

INTRODUCTION

OVERVIEW

The Education for the Future domain addresses the need to enhance access to learning and improve learning outcomes through the use of technologies, while also harnessing neuroscience research outputs relevant to learning. It addresses the urgent need to develop educators, learners and graduates who are ready to meet the demands of 4IR and to address inclusivity and sustainability challenges related to education.

South Africa must provide all of its citizens with quality education as a human right, and as the foundation for a fair society and successful economy. This is particularly relevant given the changing skills that are required as the 4IR becomes a reality. There is a widening gap between the sophistication in skills required by the 4IR and the relatively poor education that many learners currently receive. The public education system in South Africa has, repeatedly, been measured as one of the world's least effective, especially in mathematics and science. Access to education and training is not equitable, particularly in rural areas, and is falling further behind each year. Given that 2030 is one school generation away, addressing this domain is of critical importance.

ISSUES AND DRIVERS

Success in the 4IR will depend heavily on having the right skills, at a personal, business and national level. The challenge is that many jobs in the 4IR do not as yet exist and the skills needed have not yet been defined. These challenges were noted in several interviews. Input included the following: (a) Future graduates need to be prepared for a world in which AI and AI-assisted technology will play an increasingly dominant role; (b) The best strategy would be to teach skills that make humans human, rather than training students to outcompete new technologies; and (c) neuroscience research could contribute towards a better understanding of how learning outcomes could be enhanced.

At present, South Africa has severe challenges with educational outcomes and the future readiness of its workforce, especially in science, technology, engineering and mathematics (STEM). This is compounded by a severe shortage of skilled educators in this space. During stakeholder interviews the following view was expressed:

> *It is essential that we invest in STEM education for our children. This requires a focused effort. Education should not be seen as separate from science. The two belong together. –Stakeholder interview (10 October 2018)*

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 9 depicts South Africa's global research contributions in the Education domain for the period 2008 to 2018, based on data from the Scopus abstract and citation database. There is growing scientific emphasis on the Education domain. Although the number of publications is relatively low compared to other STI domains, some growth has been observed, particularly in 2014.

Since 2008, there has been a slow increase in the share of South Africa's contribution to the total scientific pool (from 0,76% to 1,22%) with a high of 1,44% in 2014. For the period 2008 to 2018, South Africa was placed 26th globally, with 4 600 publications.

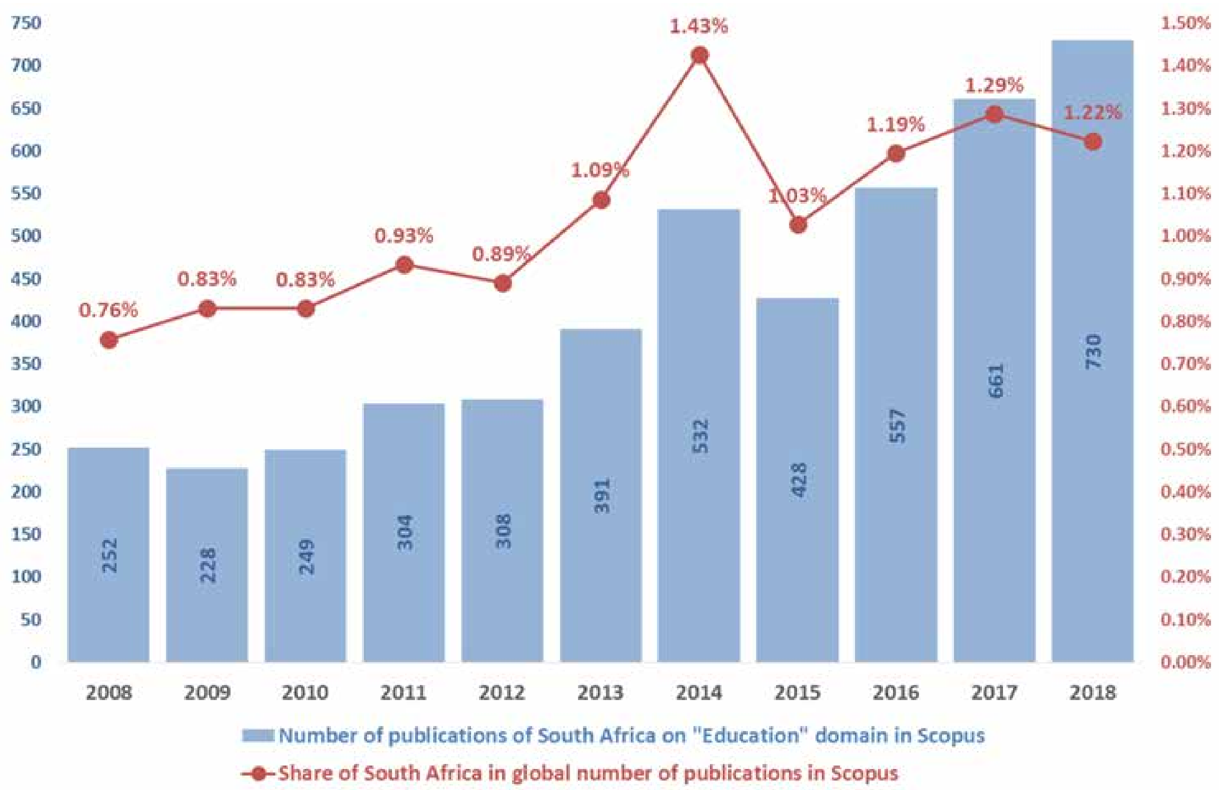

Figure 9: Publication activity related to the Education for the Future domain

Figure 10 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population size. Among the BRICS countries, South Africa produced the highest number of publications related to Education, both per GDP and per size of population.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Malaysia	7.2	314.7	22.9
Greece	4.6	203.1	22.7
Portugal	4.9	219.3	22.3
Iran	6.7	454.0	14.8
South Africa	4.6	348.9	13.2
Israel	4.5	353.3	12.7
Australia	16.7	1323.4	12.6
Spain	16.2	1314.3	12.3
UK	32.3	2637.9	12.2
Netherlands	9.7	830.6	11.7
Canada	18.0	1647.1	10.9
Austria	4.5	416.8	10.8
Sweden	5.5	535.6	10.3
Belgium	5.0	494.8	10.1
Poland	5.0	526.5	9.5
Turkey	7.2	851.5	8.5
Switzerland	5.4	679.0	8.0
Italy	15.1	1943.8	7.8
France	18.1	2582.5	7.0
Germany	23.9	3693.2	6.5
India	15.4	2650.7	5.8
US	105.0	19485.4	5.4
Russia	8.3	1578.4	5.3
South Korea	7.6	1530.8	5.0
China	58.5	12237.7	4.8
Indonesia	4.4	1015.4	4.3
Brazil	8.5	2053.6	4.1
Japan	11.3	4872.4	2.3

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Australia	16.7	24.6	67.9
Switzerland	5.4	8.5	63.5
Netherlands	9.7	17.1	56.7
Sweden	5.5	10.1	54.5
Israel	4.5	8.7	51.6
Austria	4.5	8.8	51.2
Canada	18.0	36.7	49.0
UK	32.3	66.0	48.9
Portugal	4.9	10.3	47.6
Belgium	5.0	11.4	43.9
Greece	4.6	10.8	42.8
Spain	16.2	46.6	34.8
US	105.0	325.1	32.3
Germany	23.9	82.7	28.9
France	18.1	67.1	27.0
Italy	15.1	60.5	25.0
Malaysia	7.2	31.6	22.8
South Korea	7.6	51.5	14.8
Poland	5.0	38.0	13.2
Turkey	7.2	80.7	8.9
Japan	11.3	126.8	8.9
Iran	6.7	81.2	8.3
South Africa	4.6	56.7	8.1
Russia	8.3	144.5	5.7
China	58.5	1386.4	4.2
Brazil	8.5	209.3	4.1
Indonesia	4.4	264.0	1.7
India	15.4	1339.2	1.1

Population (2017)

Figure 10: Number of publications relevant to the Education domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 11 depicts the quality of publications in the primary areas of specialisation relevant to the Education domain. The size of each bubble indicates the number of articles published for 2011 to 2015 in the given area of specialisation.

A small, but high-quality output is found in the neurosciences and multidisciplinary research. In contrast, there are substantial research outputs in the social sciences and the arts, but of a lower quality. Investment will be required to increase the quality of research outputs, particularly as it relates to STEM education and to growing neuroscience research outputs.

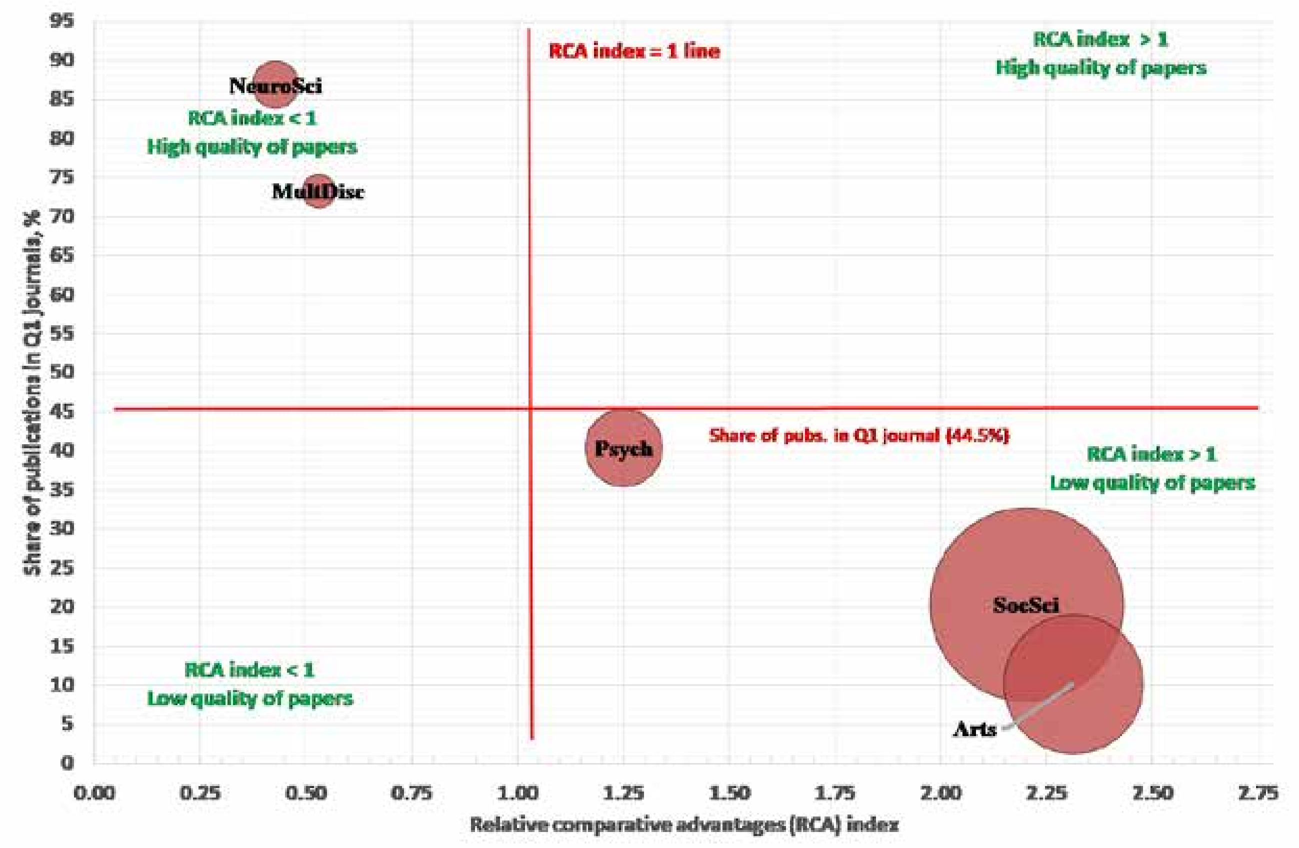

Figure 11: Quality of publications relevant to the Education domain

RECOMMENDATIONS

Three STI thrusts were identified and expanded on for the Education domain during the second phase of SAForSTI. Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

ED1: SKILLS FOR THE 4TH INDUSTRIAL REVOLUTION

This thrust addresses the need to develop the human capacity and skills required to implement the 4IR. It looks at new ways of teaching using a range of technologies such as artificial intelligence, machine learning and virtual reality to enable children, students, and employed and unemployed individuals to be trained appropriately for a future digital world. A culture of lifelong learning is supported through diverse learning channels, e.g. distance learning using apps and web-based tools. Education for all will be achieved by making use of the IoT and other technologies rather than attendance at educational institutions.

This thrust will produce a more highly skilled and self-driven workforce that is the direct outcome of a reformed education system with enhanced teaching methods. It will produce academics and educators who can deliver on new curriculum requirements and deliver globally competitive individuals and industries, as well as improved access to training opportunities by the marginalised. The outcome will be a society that is more resilient and equipped with the appropriate skills to live and work effectively in the 4IR, with higher levels of employment for all through improved education and skills development.

ED2: INCLUSIVE INNOVATION AND DEVELOPMENT

The purpose of this thrust is to align and develop STI initiatives and activities for communities, industries, academia and global partners to develop African solutions for African challenges. It addresses several requirements that are not dealt with effectively in the current innovation ecosystem and that need more attention if lifelong learning is to become a reality: (a) more early childhood development (ECD), adult basic education and training (ABET), and artisan development; (b) a strong drive to establish a sustainable circular economy; (c) the creation of more industry-driven capacity development; and (d) entrepreneurship education and training embedded in all curricula, across all disciplines.

A number of interventions are envisaged: (a) The number of ABET and artisan graduates must be increased by 2030 and funding must be provided to enable those who have not finished school to pursue ABET/artisanship opportunities; (b) introduce entrepreneurship courses in the country's high schools and develop curricula for business courses; and (c) build recycling and refurbishment plants for ICT waste (possibly at educational centres) in all provinces, underpinned by appropriate training that will generate jobs in the circular economy.

The outcome of these interventions will be a larger pool of economically active participants resulting from the increased number of people trained in entrepreneurship and innovation, and an increased number of SMME start-ups. This is fully aligned with the NDP vision of significantly increasing job creation.

ED3: CURRICULUM DEVELOPMENT 2030

This thrust addresses the need to transform the education curriculum so that entrepreneurship is embedded in all fields (STI, critical thinking and technology-enhanced learning). Research and development are needed to identify methodologies for teaching in the future (interactive, facilitated and innovative teaching methods). Investigation is also needed into how a blended learning approach could allow for the marginalised and those from poorly developed areas to have access to education and lifelong learning. Industry should be engaged to establish sector needs (using foresight) that can be incorporated into curricula. South Africa will need to engage global experts and researchers to establish and benchmark against global trends.

The outputs of this thrust are the creation of accessible electronic learning platforms and the implementation of new teaching methods using technology-enhanced and blended learning environments. This would help to create an STI culture in the learning sphere and within the community at large. While some resources are available at existing educational institutions for curriculum development, more funding will be needed to develop a new curriculum for 2030. More collaboration needs to be initiated with global experts and research institutions.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

The Education for the Future domain proposes an integrated suite of interventions, including skills development for the future, both technical (such as for AI), and soft (such as critical thinking and creative thinking), along with lifelong learning (ECD, ABET and artisan development) through industry-driven capacity development, curriculum transformation (embedding entrepreneurship education and training in all curricula across all disciplines), and also conducting R&D to identify new methodologies for teaching in the future.

The bibliometric analysis indicates that South Africa has a serious deficit of research in the STEM education areas. Current efforts are largely in the arts, social sciences and psychology, with some capacity in the neurosciences. More funding for STEM educational research is needed, including on the most relevant and appropriate solutions to build human capacity that is resilient and ready for the 4IR.

Some specific policy considerations are as follows:

- Update all existing education-related policies and regulatory frameworks, such as basic and higher education policies and the Higher Education Qualifications Framework, to be aligned with the requirements of the 4IR. For example, entrepreneurship could be embedded as part of the curriculum for all relevant fields, and entrepreneurship courses could be introduced at all high schools in the country.
- Establish a high-level committee to facilitate a skills audit to determine what 4IR skills are already in place and in which industries, and what is still needed, as well as the capacity available to undertake the required training and development.
- Implement a monitoring and evaluation function for the implementation of education policy.

CHAPTER

5

SUSTAINABLE ENERGY

INTRODUCTION

OVERVIEW

With the advancement of society, energy has become one of the basic human needs for a sustained and productive life. Although large cities in South Africa have a relatively stable energy supply, rural and peri-urban marginalised communities do not have access to reliable sources of energy. Harvesting clean and affordable energy sources (solar, wind and bioenergy) will provide opportunities for marginalised communities to adopt these new technologies, without needing to replace old technologies.

Sustainable energy technologies can leapfrog old technologies and their many limitations. Possibilities for local sustainable energy production will give communities independence, self-sufficiency and cooperation towards a common good. Decentralised local energy sources will reduce dependence on the national grid and create economic opportunities for the marginalised across South Africa. Thus, the Energy domain focuses on clean, affordable and renewable energy solutions, energy efficiency and distributed generation.

ISSUES AND DRIVERS

The water-energy-food nexus is becoming more important as climate change and its impacts are felt globally, and renewable energy will have a wide impact by 2030. In a rural context, renewables (primarily solar and wind) are particularly important. In an urban context, informal settlements could benefit from solar energy, solving the current problem of illegal connection and unpaid electricity bills.

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 12 depicts the contribution that South African researchers in the Energy domain made to the global process of knowledge generation from 2008 to 2018. There is growing scientific emphasis on the Energy domain in South Africa and the number of publications has grown faster than in other STI domains. However, South Africa's contribution to the global scientific output in the period 2008 to 2018 is still relatively low (under 1%), placing the country 39th, with 8 200 publications.

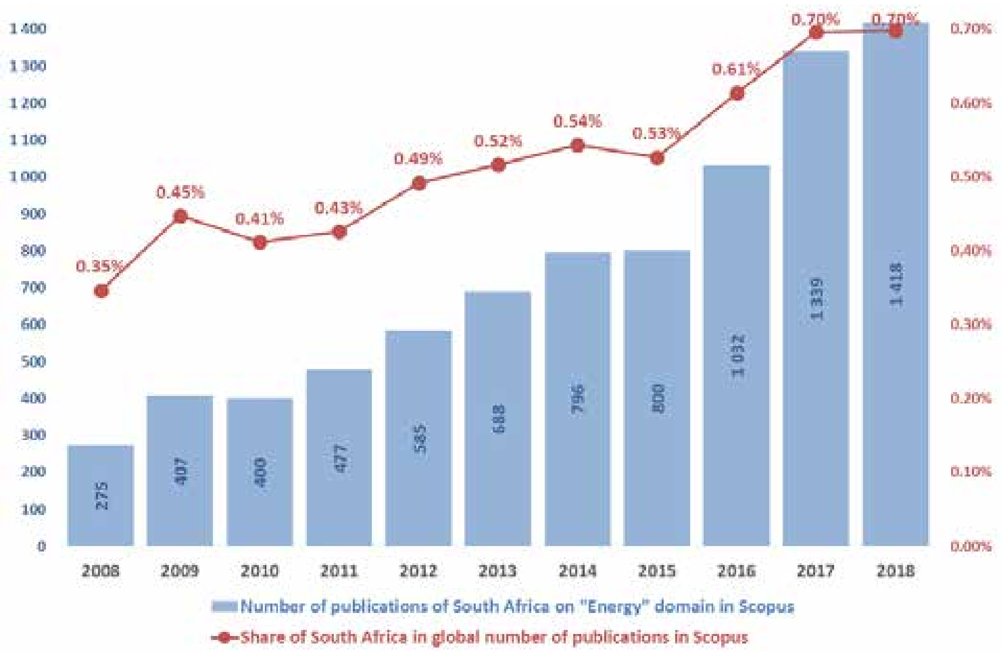

Figure 12: Publication activity related to the Energy domain

Figure 13 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population size. South Africa is placed in the middle among the BRICS countries, for both GDP and size of population.

Country	Publ ('000)	Pop (m)	Publ/Pop
Sweden	20.3	10.1	201.0
Australia	36.5	24.6	148.4
Netherlands	22.3	17.1	130.4
Canada	47.5	36.7	129.4
South Korea	56.1	51.5	108.9
UK	71.5	66.0	108.3
Germany	79.5	82.7	96.1
US	283.2	325.1	87.1
Spain	39.2	46.6	84.1
Italy	50.3	60.5	83.1
France	49.2	67.1	73.3
Malaysia	22.2	31.6	70.2
Japan	70.2	126.8	55.4
Romania	8.8	19.6	44.9
Iran	29.1	81.2	35.8
China	369.5	1386.4	26.7
Russia	37.0	144.5	25.6
Turkey	17.6	80.7	21.8
Ukraine	8.7	44.8	19.4
South Africa	8.2	56.7	14.5
Brazil	27.4	209.3	13.1
Thailand	7.7	69.0	11.2
India	88.8	1339.2	6.6
Indonesia	8.6	264.0	3.3

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Ukraine	8.7	112.2	77.6
Malaysia	22.2	314.7	70.5
Iran	29.1	454.0	64.1
Romania	8.8	211.9	41.5
Sweden	20.3	535.6	37.9
South Korea	56.1	1530.8	36.6
India	88.8	2650.7	33.5
China	369.5	12237.7	30.2
Spain	39.2	1314.3	29.8
Canada	47.5	1647.1	28.8
Australia	36.5	1323.4	27.6
UK	71.5	2637.9	27.1
Netherlands	22.3	830.6	26.8
Italy	50.3	1943.8	25.9
South Africa	8.2	348.9	23.5
Russia	37.0	1578.4	23.4
Germany	79.5	3693.2	21.5
Turkey	17.6	851.5	20.7
France	49.2	2582.5	19.1
Thailand	7.7	455.3	16.9
US	283.2	19485.4	14.5
Japan	70.2	4872.4	14.4
Brazil	27.4	2053.6	13.3
Indonesia	8.6	1015.4	8.5

GDP (2017) **Population (2017)**

Figure 13: Number of publications relevant to the Energy domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 14 depicts the quality of publications in the primary areas of specialisation relevant to the Energy domain. The size of each bubble indicates the number of articles published for 2011 to 2015 in the given area of specialisation.

South Africa is well positioned for the Energy domain in terms of the quality of publications in a number of energy and related science disciplines, viz. materials science, chemistry, biochemistry and chemical engineering. However, the relative number of publications in energy is smaller than in other areas, and additional investment will be required to expand research capacity. There are also substantial research outputs in areas such as the environment and agriculture.

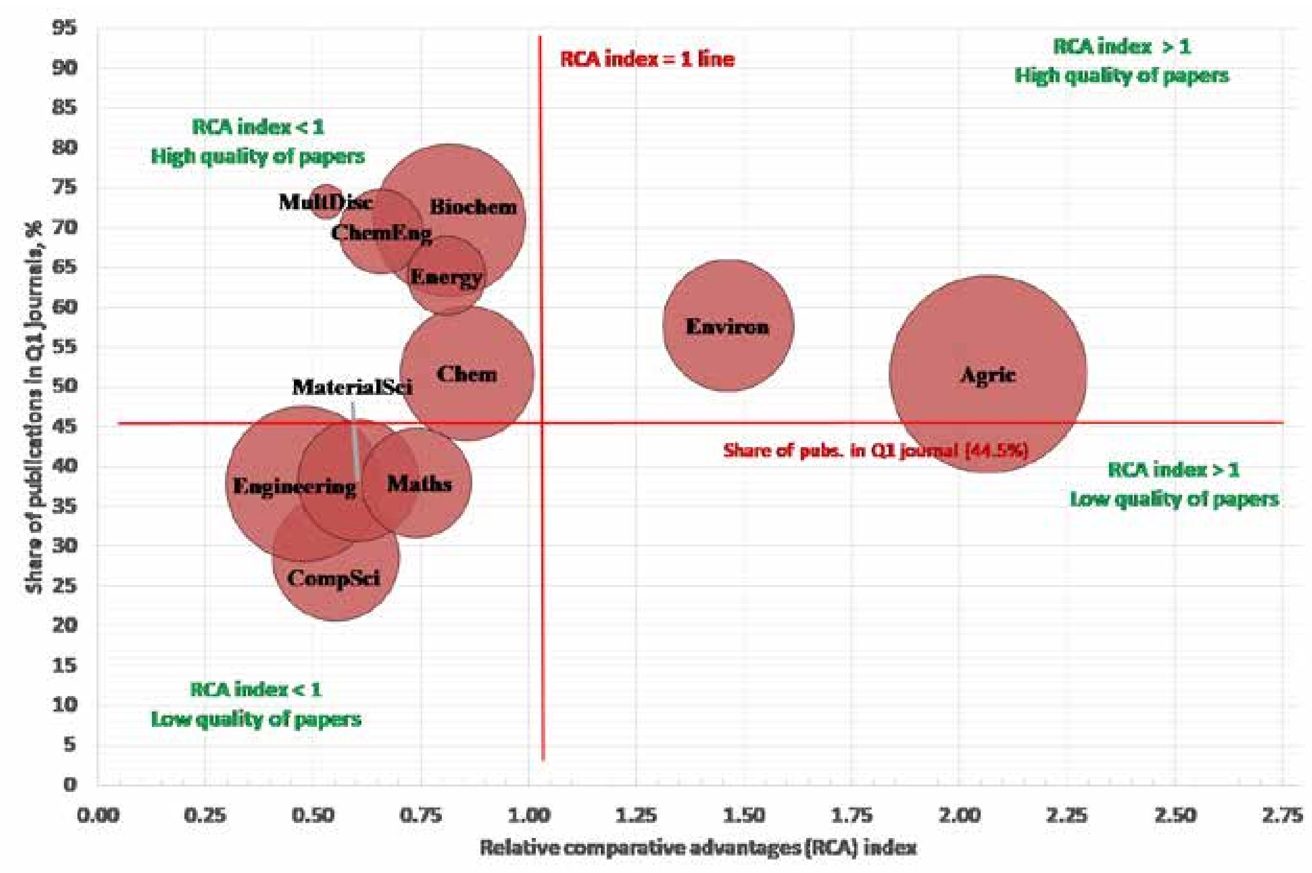

Figure 14: Quality of publications relevant to the Energy domain

RECOMMENDATIONS

Four STI thrusts for the Energy domain were identified and elaborated on during the second phase of SAForSTI. Summaries of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

EN1: CLEAN, AFFORDABLE AND SUSTAINABLE ENERGY FOR ALL

This thrust aims to optimise the cost of energy provision to make it affordable and sustainable, and easily accessed by all, especially the marginalised. It will also provide solutions for mobility, industry and household use, with increased self-reliance to meet energy needs. Through the use of new generation technologies and energy-efficient solutions, it aims to close the energy gap left by decommissioned coal plants that have reached the end of their useful lives, thereby contributing towards developing a green economy. The thrust will explore diverse generation and storage technology options for affordable micro and small-generation solutions, including their manufacture.

South Africa has relevant expertise, but this is located in different institutions with diverse focal areas and limited collaboration on national programmes that respond to local energy transition topics. International partnerships are critical in this space, but local technical capacity must be built, and the research should be conducted by local experts using local laboratories/institutes as far as possible. The thrust will require changes in policies related to electricity and related services provision if the country is to transition toward a low carbon electricity supply.

The country has abundant solar and wind energy resources to achieve this thrust. However, the implementation of this new low carbon energy dispensation has to benefit the whole of society. If the results are not achieved, the country is likely to miss its targets for carbon emission reduction, and the cost of energy provision will be much higher. Communities that are affected by high pollution levels, generally the most marginalised, will continue to suffer adverse health effects.

EN2: RENEWABLE ENERGY SOURCES AND TECHNOLOGIES

The focus of this thrust is on the migration of energy sources from carbon-intensive coal to cleaner and renewable sources. This applies to micro and medium generation with a shorter time frame of 10 years, as well as to baseload generation with a longer time frame of 50 years. It addresses the need to find solutions to climate change threats, the relatively high cost of micro-generation, and the lack of affordable technologies for renewable energy production, as well as potential conflicts related to the use of crops for biofuels versus food. The result will significantly increase the share of renewables in the country's energy mix, save on carbon taxes and reduce South Africa's carbon footprint. It will also result in more distributed job creation in renewable energy generation and stimulate economic activity in rural areas due to the distributed nature of some renewable energy generation technologies. A spin-off benefit will be the spreading of the risk associated with energy supply security.

Standard models for creating community-based mini or micro-grids will need to be designed to incorporate existing technologies. Optimised technologies to generate bioenergy from these resources must be researched and developed. Demonstration micro-grids need to be established and validated. Scale-up operations will require partnerships with independent power producers and state-owned enterprises, and training and skills development programmes to build the necessary expertise to facilitate the establishment of compliant micro-grid systems. High-level coordination of the distributed micro-grids and integration into the national grid will be critical to the success of such a system.

EN3: ENERGY EFFICIENCY SOLUTIONS FOR INDUSTRY AND HOUSEHOLD USE

This thrust has a focus on the provision of affordable energy-efficient devices, technologies and energy management for both household and industrial applications. It addresses the need for large-scale adoption of energy-efficient devices, and the dissemination of knowledge about them. The thrust should result in significant reductions in energy wastage and increases in energy efficiency results that will benefit the marginalised, as they will be able to use the savings to meet other needs.

Several interventions are required: (a) screening of appropriate energy-efficient technologies and the identification of ways of adapting such technologies through R&D; (b) a technology validation programme to support testing and the certification of energy saving devices, and incentives to stimulate the uptake of energy-saving technologies; and (c) training of consumers in energy-saving devices and incentives to change behaviour and use energy frugally.

A centre of expertise needs to be established, and funded, to coordinate and drive implementation. Focused research and technology development programmes need to be initiated at relevant institutions. Support should continue for existing successful initiatives.

EN4: DISTRIBUTED ENERGY GENERATION AND STORAGE

This thrust concerns the private and communal generation and storage of energy which would be enabled from micro to small scale. Both off-grid and grid-tied systems are addressed. The current energy system is made up of a centralised monopoly in generation and distribution, with limited opportunities for small players to get involved in energy beyond their own consumption. The thrust addresses the potential of the private generation of electricity, and empowering excluded communities to generate their own affordable power, thus stimulating local economic growth. This opportunity will also give small businesses greater control over their electricity costs.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

Given the ongoing energy crisis in South Africa, and its effects on the economy and broader society, alternatives for sustainable energy production in the country are of critical importance. South Africa shows a growing scientific emphasis on the Energy domain, with the number of publications growing faster than in the other STI domains. However, its specialised capacity in key fields, such as energy, chemistry, chemical engineering and biochemistry is insufficient and will require significant further investment if it is to meet the energy demands of a growing population and the need for sustainable economic growth.

CHAPTER

6

FUTURE OF SOCIETY

INTRODUCTION

OVERVIEW

The Future of Society domain addresses the meta-dimension of inequality and unequal access to technology in the country, and how challenges in the enabling environment can be overcome. Consideration is given to addressing barriers and harnessing opportunities to overcome unequal access to technology, closing the digital divide and driving digital inclusion. This is a cross-cutting domain that will ensure a more socially responsive approach to implementation in all the other domains and their associated thrusts. It provides a social lens that will enable each of the thrusts to achieve their objectives in a more socially responsive manner.

ISSUES AND DRIVERS

There are many barriers that result in unequal access to technology, e.g. patriarchal, legal, institutional, economic, socio-cultural and class barriers, which affect the poor, vulnerable and marginalised in particular. Questions were raised about how these groups could appropriate technology in the 4IR, what technological opportunities could be harnessed to overcome the technological/digital divide, and how equal access could result in better employment opportunities among marginalised and vulnerable groups.

One of the major issues raised is that policy makers and government departments, the private sector and civil society players, are not working across domains to respond effectively to complex societal challenges and to make technologies work for the social good. To add to this complexity, innovation is market-driven and lies largely outside public policy-making processes; it does not always consider the social aspects of technology.

Previous national STI policy placed little emphasis on local, community-based R&D and social innovation. Policy instruments need to be developed to enable the inclusive appropriation of technology, with possible restructuring or redesign of existing institutions or the possible establishment of new institutions that are strongly positioned within the economy. A pro-African/pan-African NSI is needed, with RDI programmes that encourage pan-African collaboration.

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 15 depicts the contribution by South African researchers to the global process of knowledge generation related to the Future of Society domain during the period 2008 to 2018. Overall, there has been growth in emphasis on research relevant to the Future of Society domain in South Africa, with a sharp rise since 2016. South Africa's share of the global scientific output relevant to this domain has also increased, except for a sharp drop between 2008 and 2009, and a slight drop from 2014 to 2016. The country is placed 11th globally, with 1 164 publications.

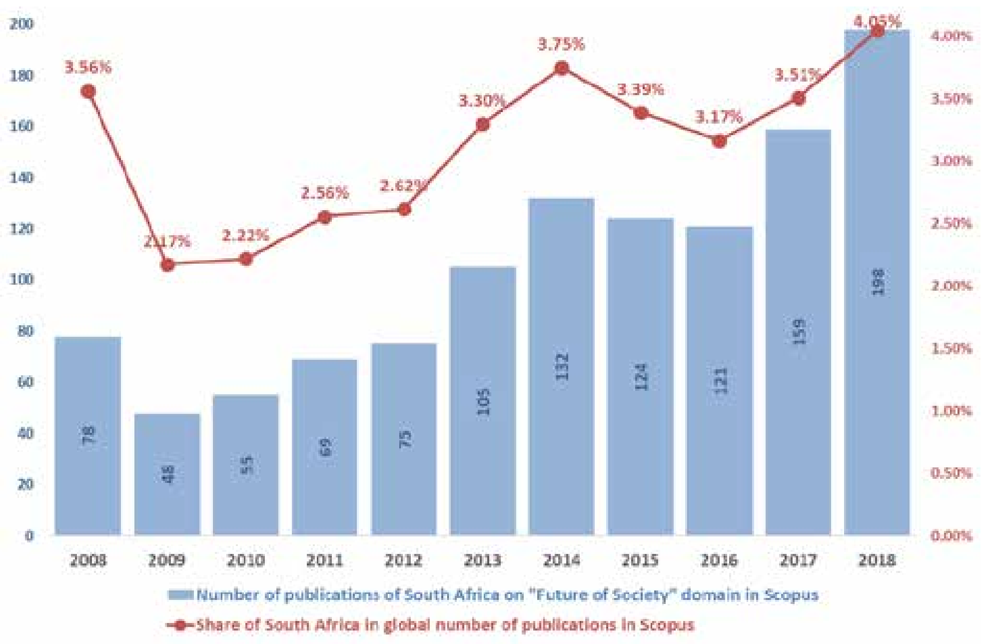

Figure 15: Publication activity related to the Future of Society domain

Figure 16 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population size. Among the BRICS countries, South Africa produced by far the highest number of publications related to the Future of Society domain, both per GDP and per size of population.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
South Africa	1164.0	348.9	3336.5
Finland	629.0	252.3	2493.0
Netherlands	1712.0	830.6	2061.2
Sweden	1020.0	535.6	1904.4
Denmark	594.0	329.9	1800.7
UK	4487.0	2637.9	1701.0
Norway	638.0	399.5	1597.0
Belgium	746.0	494.8	1507.8
Australia	1802.0	1323.4	1361.6
Malaysia	426.0	314.7	1353.6
Austria	532.0	416.8	1276.3
Nigeria	429	375.7	1141.7
Switzerland	726.0	679.0	1069.3
Canada	1637.0	1647.1	993.9
Spain	1248.0	1314.3	949.5
Italy	1303.0	1943.8	670.3
Russia	974.0	1578.4	617.1
Germany	2217.0	3693.2	600.3
France	1354.0	2582.5	524.3
Brazil	904.0	2053.6	440.2
India	1148.0	2650.7	433.1
US	8121.0	19485.4	416.8
South Korea	471.0	1530.8	307.7
China	3102.0	12237.7	253.5
Japan	1113.0	4872.4	228.4

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Norway	638.0	5.3	12037.7
Finland	629.0	5.5	11419.3
Denmark	594.0	5.8	10241.4
Sweden	1020.0	10.1	10099.0
Netherlands	1712.0	17.1	10011.7
Switzerland	726.0	8.5	8541.2
Australia	1802.0	24.6	7325.2
UK	4487.0	66.0	6798.5
Belgium	746.0	11.4	6543.9
Austria	532.0	8.8	6047.1
Canada	1637.0	36.7	4460.5
Germany	2217.0	82.7	2680.8
Spain	1248.0	46.6	2678.1
US	8121.0	325.1	2498.0
Italy	1303.0	60.5	2153.7
South Africa	1164.0	56.7	2052.9
France	1354.0	67.1	2017.9
Malaysia	426.0	31.6	1347.1
South Korea	471.0	51.5	914.6
Japan	1113.0	126.8	877.8
Russia	974.0	144.5	674.0
Brazil	904.0	209.3	431.9
Nigeria	429	190.9	224.7
China	3102.0	1386.4	223.7
India	1148.0	1339.2	85.7

Population (2017)

Figure 16: Number of publications relevant to the Future of Society domain (normalised by GDP and population)

PUBLICATION QUALITY

Figure 17 depicts the quality of publications in the primary areas of specialisation relevant to the Future of Society domain. The size of each bubble indicates the number of articles published for 2011 to 2015 in the given area of specialisation. Given the multidisciplinary and cross-cutting nature of this domain, a large range of publications from varied disciplines are relevant. In general, publications in the natural and physical sciences are of higher quality (a greater share are published in first quartile journals) when compared with publications in the social sciences and economics. On the other hand, the degree of specialisation in the social sciences and economics is greater than in the natural and physical sciences.

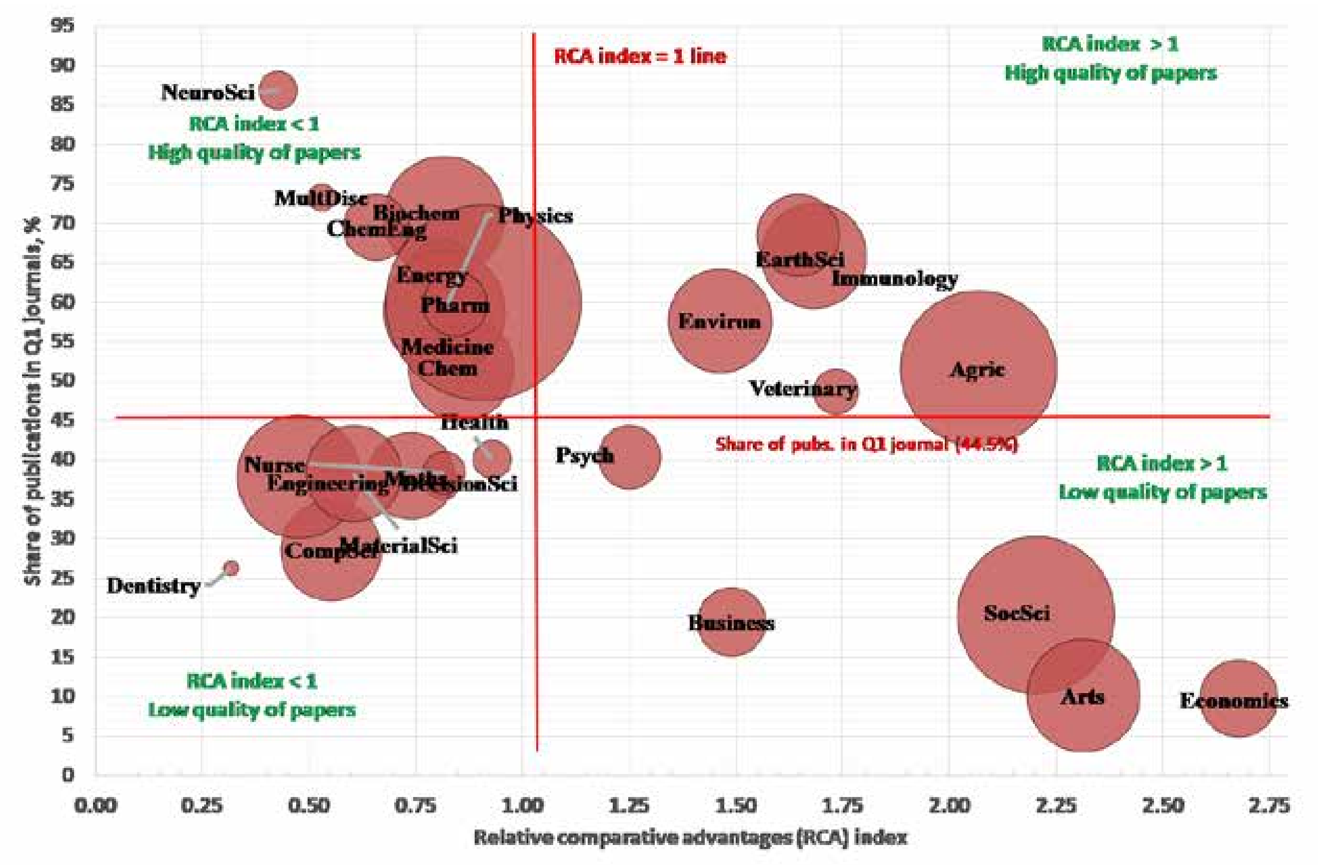

Figure 17: Quality of publications relevant to the Future of Society domain

RECOMMENDATIONS

Two STI thrusts for the Future of Society domain were identified and elaborated on. Summaries of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

FS1: POLICIES AND INDICATORS FOR STI IN A CHANGING SOUTH AFRICAN SOCIETY

Current STI interventions do not address societal challenges adequately and a "science for all" approach, that benefits everyone, needs to be supported more proactively. This thrust therefore aims to develop STI policies that appropriately address the harnessing of STI in the context of South Africa's societal challenges at national, local and community levels. It also addresses the need for relevant STI indicators, underpinned by a sound research base and supported by a sufficiently resourced monitoring and evaluation system. The thrust is cross-cutting with respect to the other identified STI domains and their associated thrusts. It is also fully aligned with the SDGs, and it supports efforts to eliminate poverty, reduce inequality, and promote employment in the country.

Research, based on international good practice and experience needs to be initiated to develop a more relevant set of STI indicators (including societal indicators). An appropriate and relevant monitoring and evaluation system will place equal emphasis on societal indicators and existing STI indicators. Adequately resourced governance systems to implement effective monitoring and evaluation will result in learning and actively promote change in institutions, communities and stakeholders in the NSI to effect societal change through the use of technology for the social good. Existing STI (and any other related) policies should be reassessed and changed to include societal issues as a cross-cutting issue in relevant STI domains. Policy instruments to support community self-sufficiency need to be included.

FS2: STI FOR INCLUSIVE, PEOPLE-LED DEVELOPMENT

South Africa needs to be able to use its scientific and technological capacities, capabilities and competences better to confront enduring and persistent economic, social and political challenges. This thrust presents options that could facilitate and promote these changes. The NSI needs to become people-centred and ecologically sensitive. Holistic and cross-cutting initiatives are required to rebuild trust within the NSI – between the state and citizens, the public and private sectors, and the knowledge worker and research community.

Current STI initiatives show a bias towards technological innovations for narrow economic competitiveness, and away from innovations for social benefit and the public good, with insufficient attention being paid to either social, political or ecological constraints on their utilisation. There is insufficient focus on major socio-economic problem-solving in South Africa, and not enough focused R&D activity that provides solutions. There are also very significant challenges in preparing for the labour transition that is imminent in the 4IR.

This thrust includes the formulation of a national framework for prioritising R&D to guide all NSI players, based on domestic needs, community/social/grassroots innovation, and global ecological conditions.

Programmes for technology demonstration and technology-based pilots that promote social and technological innovation need to be expanded, extended and strengthened. A technology appropriation fund and/or a preferential procurement programme could enable communities to become technology providers and to scale up existing (successful) pilots in prioritised areas – these need to be identified and efforts made to replicate successful models on a national scale.

STI mobility studies are needed to better understand the movement of those with STI skills, and to further encourage the building, maintenance and expansion of South Africa's scientific and technological capabilities. Significant investment will also be needed to support applied social science and humanities-based research that enables the harnessing of STI to be examined within the context of social innovation.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

Given the importance of social innovation in the present and future NSI, more attention is needed to create an enabling environment that gives emphasis to the human and social sciences to enable the optimal harnessing of innovations and new technologies for the benefit of society. Research outputs related to the Future of Society domain will require close monitoring to track whether collaborative research improves in this area, and to ensure that research translates into implementable and successful scaled-up programmes for the social good.

The development of policies and policy instruments to strengthen the emphasis on "science for all" will necessarily have far-reaching impact and implications for policy related to multiple sectors. Similarly, the development and implementation of an associated set of STI indicators, if effective, will result in systemic adjustments and realignments to achieve desired policy goals.

Some specific policy considerations are as follows:

- Existing STI-related policies should be reassessed and modified to include societal issues cutting across all sectors and domains. For example, policy instruments should be put in place to support community self-sufficiency.
- The monitoring of the implementation of STI-related policy, using appropriate indicators, should be given priority. For example, existing monitoring and evaluation systems should be enhanced to include social innovation in their scope.
- The development and updating of STI-related policies should include the active participation of all sectors of society, and especially participation by those sectors that have been excluded in the past.
- Establish instruments that facilitate partnerships between all NSI players, including communities. For example, establish a forum to promote social innovation, or to identify action plans to address issues of social inequality.

CHAPTER

7

HEALTH INNOVATION

INTRODUCTION

OVERVIEW

Health is a key STI domain for South Africa. It should be focused on meeting the needs of local marginalised communities, rather than the adopting and adapting of imported health solutions developed for affluent First World populations. The domain is integrally linked to the challenges the country faces in terms of poverty, with poor living conditions inevitably leading to poor health. The impact of climate change on human health, particularly the marginalised, also needs to be better understood. Innovative local solutions have the potential to be transferred to the rest of Africa, providing jobs and generating revenues. Overall, the South African health system needs to be optimised to improve healthcare and drug development, and to deliver better diagnostic and treatment services.

Inadequate current health infrastructure and administration, particularly in the rural areas of South Africa, needs to be improved through the use of emerging technologies such as mobile applications, nanotechnology and imaging technologies, AI and big data analytics. Integrated, innovative, multidisciplinary applications of new technologies for the health of marginalised people is needed, especially focused on preventive strategies.

ISSUES AND DRIVERS

Increasingly rapid technological innovation will have a large impact on the provision of health service. As noted by one interviewee:

> ***There will be a revolution in medical practice. It will not be do-it-yourself medicine, but increasingly there will be the modern equivalent of the 'barefoot doctor' who is empowered through advances in technologies. Many health services could in future be offered at home. – Stakeholder interview (8 October 2018).***

The use of statistical and dynamic models to improve decision-making in clinical medicine and public health is a key issue, as is the role of data science through the application of big data analytics and machine learning.

Current health research will increasingly be linked to the molecular sciences. New diagnostic tools will bring to light more diseases, resulting in the need for new treatments. New synthetics and bio-identicals are important, especially to decrease unwanted side-effects. Personalised medicine, taking into account the different responses of individuals to different diets and medications, is rapidly becoming a future reality. This will require research on the sources of lifestyle-related diseases, and what genetic predispositions are linked to these diseases. The role of precision medicine in health treatment also needs to be assessed. All of these developments will require a re-examination of cost structures, and how these need to be changed to meet the health needs of all.

South Africa has a diverse population that could be used as a platform to study, prevent and treat disease, for the benefit of the health of people globally. For example, this could be a major advantage in developing gene therapies with wider applications elsewhere in the world. South Africa also has a strong veterinary research capability that could, in conjunction with its diverse population, form the basis for research leadership in diseases transmitted from animals to humans.

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 18 depicts the contribution by South African researchers to global knowledge generation in the Health domain from 2008 to 2018. The figure indicates that there is growing emphasis in South Africa on research that is relevant to this domain. The number of publications is considerably higher than in other STI domains identified in the foresight study. The number of publications has been growing steadily, as has South Africa's share of the global scientific output (31st, with 60 500 publications for the period 2008 to 2018).

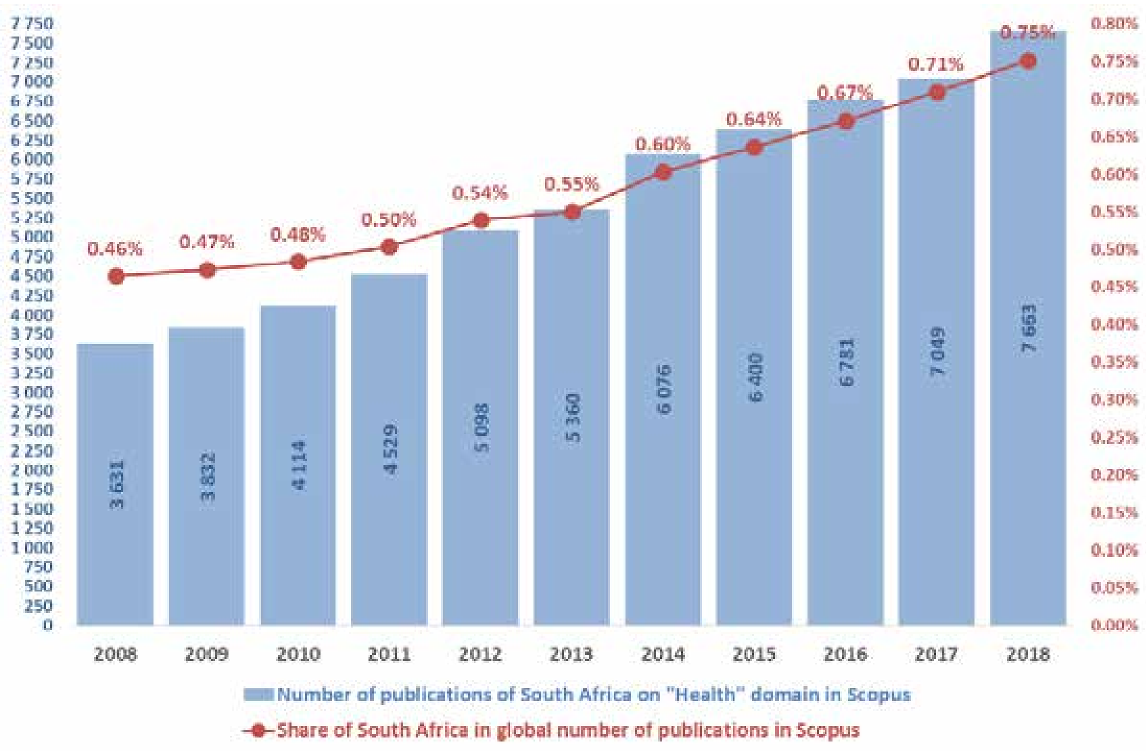

Figure 18: Publication activity related to the Health domain

Figure 19 depicts publication activity during the period 2008 to 2018 relative to other countries. The number of publications produced has been normalised according to both GDP and population size. Among the BRICS countries, South Africa produced the highest number of publications related to the Health domain per GDP, and the second highest per size of population.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Netherlands	284.5	830.6	342.5
UK	833.3	2637.9	315.9
Iran	138.5	454.0	305.1
Sweden	161.7	535.6	301.9
New Zealand	58.5	204.1	286.6
Belgium	138.0	494.8	278.9
Czech Republic	60.2	215.9	278.8
Australia	365.3	1323.4	276.0
Switzerland	186.3	679.0	274.4
Canada	438.4	1647.1	266.2
Spain	331.1	1314.3	251.9
Egypt	55.6	235.4	236.2
Poland	124.2	526.5	235.9
Italy	443.7	1943.8	228.3
Turkey	192.3	851.5	225.8
Germany	640.8	3693.2	173.5
South Africa	60.5	348.9	173.4
Ireland	56.2	331.4	169.6
South Korea	258.1	1530.8	168.6
France	409.6	2582.5	158.6
US	3029.6	19485.4	155.5
India	380.3	2650.7	143.5
Brazil	264.1	2053.6	128.6
Japan	524.4	4872.4	107.6
China	914.4	12237.7	74.7
Mexico	64.2	1150.9	55.8

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Switzerland	186.3	8.5	2191.8
Netherlands	284.5	17.1	1663.7
Sweden	161.7	10.1	1601.0
Australia	365.3	24.6	1485.0
UK	833.3	66.0	1262.6
New Zealand	58.5	4.8	1218.8
Belgium	138.0	11.4	1210.5
Canada	438.4	36.7	1194.6
Ireland	56.2	4.8	1168.1
US	3029.6	325.1	931.9
Germany	640.8	82.7	774.8
Italy	443.7	60.5	733.4
Spain	331.1	46.6	710.5
France	409.6	67.1	610.4
Czech Republic	60.2	10.6	567.9
South Korea	258.1	51.5	501.2
Japan	524.4	126.8	413.6
Poland	124.2	38.0	326.8
Turkey	192.3	80.7	238.3
Iran	138.5	81.2	170.6
Brazil	264.1	209.3	126.2
South Africa	60.5	56.7	106.7
China	914.4	1386.4	66.0
Egypt	55.6	97.6	57.0
Mexico	64.2	129.2	49.7
India	380.3	1339.2	28.4

Population (2017)

Figure 19: Number of publications relevant to the Health domain (normalised by GDP and population)

PUBLICATION QUALITY

Figure 20 depicts the quality of publications in the primary areas of specialisation relevant to the Health domain. The size of each bubble indicates the number of articles published for the period 2011 to 2015 in the given area of specialisation. South Africa produced high-quality publications in numerous disciplines relevant to the Health domain, including in medicine, immunology, pharmaceuticals, biochemistry and neuroscience. However, with the exception of immunology, the degree of specialisation in these areas is modest. There is significant specialised capacity in the social sciences, but the quality of the publications is significantly lower.

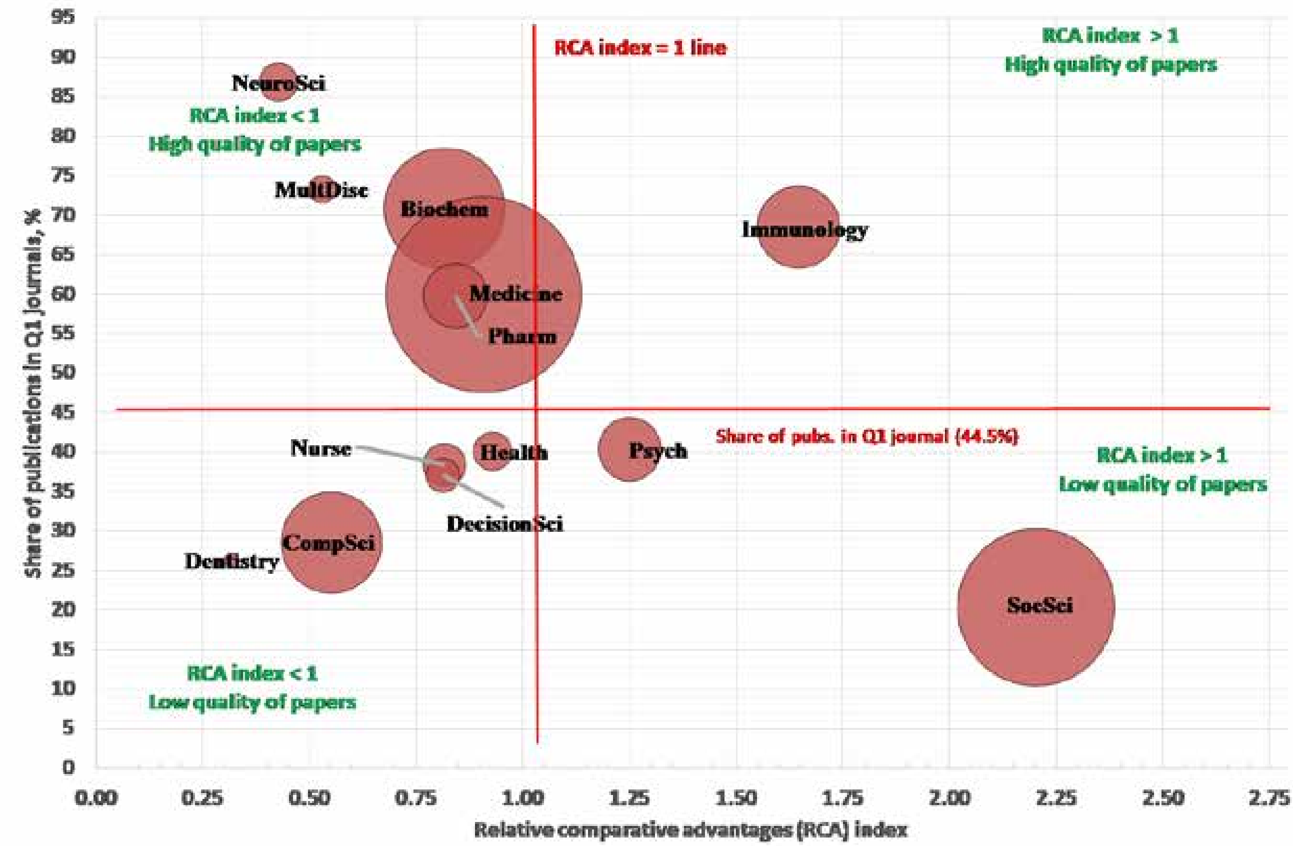

Figure 20: Quality of publications relevant to the Health domain

RECOMMENDATIONS

Three STI thrusts were identified and elaborated on for the Health domain during SAForSTI. Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

HE1: OPTIMISATION OF HEALTH SYSTEMS

This thrust addresses the optimisation of healthcare through the provision of quality support systems and equitable resource allocation. The current healthcare system is characterised by slow supply chains, poorly managed procurement systems and long turnaround times in providing diagnostic information to healthcare staff and patients. Infrastructure problems in publicly funded medical facilities have resulted in poor safety and hygiene, erratic power supply and poor water quality. Lack of coordination and poor data management between facilities has resulted in inefficient healthcare systems. All of these problems have cost lives.

The outcomes of this thrust will be optimised procurement and delivery systems to ensure reliable access to supplies at all facilities. Rapid diagnosis technologies will be available at the point of care, with immediate access to test results through the use of mobile apps and improved informatics systems. Reliable, well-managed facilities and efficient hospital infrastructure will be available in all locations, and patient data will be recorded timeously and accurately in a high-quality national data system. This will result in improved responsiveness and robustness of the healthcare system. The benefits of the thrust will be greater for those who access healthcare through the public sector system rather than through the private sector.

Significantly improved data is required on the location of all healthcare facilities and their current access to critical resources, improved morbidity and mortality data. Data on transportation infrastructure will be necessary for the optimised distribution of resources. Research needs include modelling, simulation and the development of algorithms that can be used to evaluate alternative scenarios for allocating resources. Knowledge and expertise in operations research and algorithm development, modelling, simulation and big data analytics are required, all of which are currently in short supply in South Africa.

This thrust will benefit from the outputs of the Digitisation of Health Systems thrust, which will provide critical new data on population-level health patterns and needs.

HE2: IMPROVING THE QUALITY OF HEALTHCARE

This thrust addresses a range of issues to ensure the provision of affordable and high-quality healthcare to all South Africans, regardless of location or economic status. The South African healthcare system faces a serious shortage of expert staff at all healthcare facilities, and poor access to appropriate facilities in most communities, including access to digital information. This thrust aims to improve the prevention, diagnostics, and treatment strategies required for the management of the disease burden, from behavioural management to vaccinations, point-of-care diagnostics and new drugs. This includes the use of advanced technologies, e.g. precision and personalised medicine for predictive and diagnostic applications. The need for the digitisation of health systems and a range of strategies and technologies for reducing the rates of communicable and non-communicable diseases is fundamental. Widespread access is needed to world-class technologies for diseases that are difficult (expensive) to diagnose and treat.

These systems should result in fully operational supply-chain and procurement systems that are optimised for decentralisation and are fully scalable. Improvements will be needed in the different tiers of governance within the healthcare system to optimise their functioning.

HE3: DIGITISATION OF HEALTH SYSTEMS

The aim of this thrust is to develop a high-quality national unified patient data system that provides for (a) all people to be recorded in the system; (b) all healthcare systems to be digitised and integrated; and (c) all medical practitioners and healthcare workers to be using life-long learning tools that are regularly updated with current and reliable information. The thrust will also address the need for telemedicine and remote surgery applications, and the use of remote diagnosis using AI.

There are currently significant delays and inefficiencies in patient care due to the lack of an integrated, reliable and up-to-date (local, provincial and national) electronic health system. The current healthcare system does not record and maintain patient data. There are also not enough healthcare workers and training programmes to maintain such a system.

The outcome of this thrust is a comprehensive, universal, secure, national patient record system, underpinned by technology-assisted expansion and support options, that will allow the effective use of available healthcare skills in rural and underserviced areas. It will make provision for effective diagnosis/decision-support systems in all communities and provide an ongoing programme for training medical staff, including electronic training. The system will allow full access to patient records throughout, from cradle to grave, by all healthcare facilities. Using big data analytics, the system will collate population and time-series datasets for the whole population. This will be encrypted and secure to comply with the Protection of Personal Information Act. The system will allow access to high-quality medical solutions in all communities, with improved diagnosis and treatment options.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

The three thrusts in the Health domain address the optimisation of healthcare through the provision of quality support systems and equitable resource allocation, enabled by better supply and procurement systems and rapid diagnostics systems. This includes the creation of an integrated national patient record system that can be accessed by all healthcare practitioners, including in those in remote and isolated areas. The development of improved telemedicine and remote diagnostics systems will support expanded roles for healthcare workers as well as the longer-term likelihood of increased self-directed healthcare in the home. The application of ICT to healthcare will contribute towards creating a healthier population, for the benefit of everyone.

Although there has been growth in scientific research output in the Health domain in South Africa, there is a need for more collaborative research between the natural and social sciences to better understand the drivers for and any challenges to the adoption of the proposed healthcare systems. An investment strategy is required to improve the quality of relevant social science research outputs, and further research is needed to understand the change management processes and learning requirements for optimal use and adoption of technologies to support and enhance healthcare services.

Some specific policy considerations are as follows:

- An assessment of the functioning of the difference tiers of governance of the healthcare system, including policy and regulatory aspects, should be undertaken, and improvements introduced where necessary.
- Policy and regulatory frameworks should be developed to ensure robust, interoperable and secure data systems for the long-term storage of patient data and other related information. Funding for these systems will also be necessary.
- A health data policy should be developed to addresses issues such as privacy, ethics and cybersecurity.

CHAPTER

8

HIGH-TECH INDUSTRIALISATION

INTRODUCTION

OVERVIEW

South Africa needs to embrace advanced manufacturing approaches rapidly to improve competitiveness and arrest further job losses and deindustrialisation likely to emerge as the 4IR approaches. The High-tech Industrialisation domain includes advanced manufacturing and technologies such as robotics, artificial intelligence (AI), IoT and additive manufacturing.

The 4IR will change the way things are produced, with large-scale automation needed to meet the requirements for high volume manufacture. This will be supported by large data exchange capabilities and cloud computing infrastructure in manufacturing environments. The efficiency of production systems will improve through the establishment of smart factories operated by intelligent manufacturing machines and cyber-physical systems.

South Africa has pockets of advanced manufacturing excellence, for example in additive manufacturing, but these need to be taken to the next level. The country needs to find niche areas in which it has the potential to be globally competitive and to focus efforts on the beneficiation of its natural resources through the application of advanced manufacturing systems. Advanced manufacturing could create opportunities for new SMMEs in South Africa.

> ***We need to realise that there is no opportunity for us to be a leader in automation in the world. We need to think like Italy: do small-scale, high-quality manufacture.***
> ***– Stakeholder interview (2 August 2018).***

ISSUES AND DRIVERS

With relatively little existing infrastructure compared to developed countries, South Africa could leapfrog into the future by deploying 4IR infrastructure and tapping into its youthful population. However, this will require major investments in new digital infrastructure that will support, for example, big data, data analytics and machine learning. The number of task-based jobs will dwindle as these are taken on by robots, and labour-intensive jobs and jobs that involve simple judgement are likely to disappear. The education system will need to change significantly to ensure that workers are reskilled, and that school-leavers have the right skills to meet the changing workplace demands. One of the stakeholders interviewed stated as follows:

> ***In essence, automation creates a huge problem for employment in South Africa, and we haven't yet found a way around it. –Stakeholder interview (2 August 2018).***

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 21 depicts the contribution of South African researchers to the global process of knowledge generation related to high-tech industrialisation during the period 2008 to 2018. The figure indicates that there is fast-growing scientific emphasis on the High-tech Industrialisation domain in South Africa. The number of publications has been growing steadily, particularly in the last three years. South Africa's share of the global scientific output in this domain has increased. However, it is still very low (about 0,5%, placing it 41st globally, with 32 500 publications).

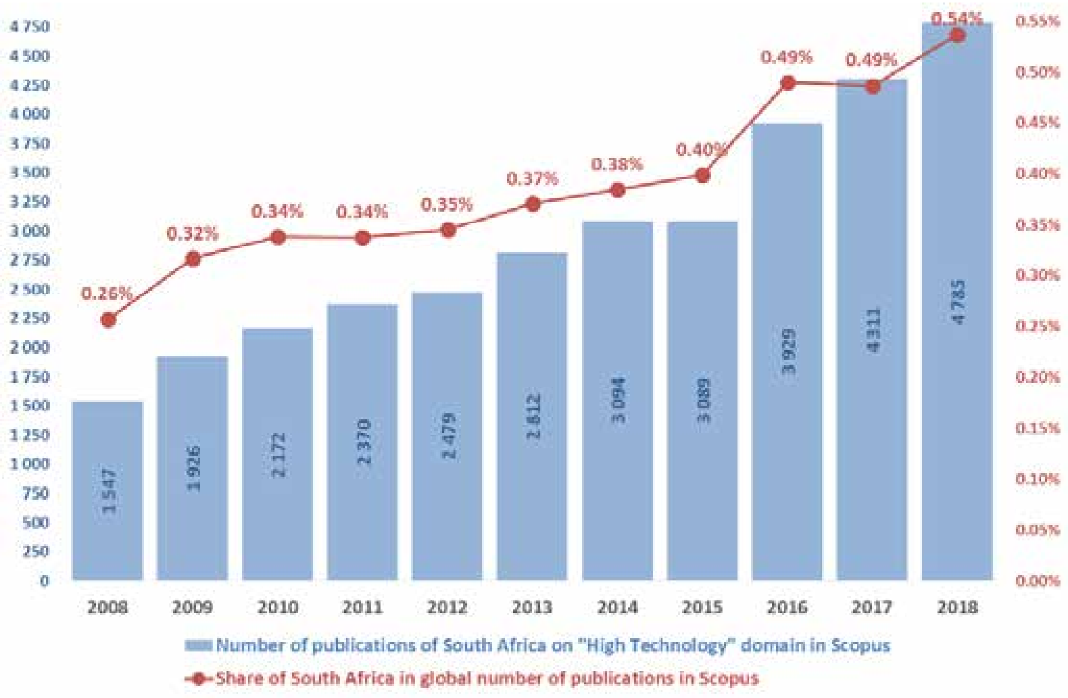

Figure 21: Publication activity related to the High-tech Industrialisation domain

Figure 22 depicts publication activity during the period 2008 to 2018, relative to other countries. The number of publications produced has been normalised according to both GDP and population. Among the BRICS countries, South Africa is the second lowest producer of publications relevant to the High-tech Industrialisation domain, per GDP and per population size.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Iran	161.8	454.0	356.4
Ukraine	37.3	112.2	332.6
Malaysia	103.3	314.7	328.2
Poland	122.2	526.5	232.1
South Korea	298.4	1530.8	194.9
China	2145.5	12237.7	175.3
India	432.6	2650.7	163.2
Spain	203.5	1314.3	154.8
Canada	241.1	1647.1	146.4
UK	382.4	2637.9	145.0
Australia	180.9	1323.4	136.7
Netherlands	112.9	830.6	135.9
Italy	258.0	1943.8	132.7
Germany	430.0	3693.2	116.4
Russia	182.3	1578.4	115.5
France	297.3	2582.5	115.1
Turkey	92.8	851.5	109.0
Pakistan	30.3	305.0	99.4
Ireland	31.5	331.4	95.0
Japan	456.6	4872.4	93.7
South Africa	32.5	348.9	93.2
US	1505.2	19485.4	77.2
Brazil	134.1	2053.6	65.3
Indonesia	33.2	1015.4	32.7

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Australia	180.9	24.6	735.4
Netherlands	112.9	17.1	660.2
Canada	241.1	36.7	656.9
Ireland	31.5	4.8	654.7
South Korea	298.4	51.5	579.4
UK	382.4	66.0	579.4
Germany	430.0	82.7	520.0
US	1505.2	325.1	463.0
France	297.3	67.1	443.1
Spain	203.5	46.6	436.7
Italy	258.0	60.5	426.4
Japan	456.6	126.8	360.1
Malaysia	103.3	31.6	326.6
Poland	122.2	38.0	321.6
Iran	161.8	81.2	199.3
China	2145.5	1386.4	154.8
Russia	182.3	144.5	126.2
Turkey	92.8	80.7	115.0
Ukraine	37.3	44.8	83.2
Brazil	134.1	209.3	64.1
South Africa	32.5	56.7	57.3
India	432.6	1339.2	32.3
Pakistan	30.3	197.0	15.4
Indonesia	33.2	264.0	12.6

Population (2017)

Figure 22: Number of publications relevant to the High-tech Industrialisation domain (normalised by GDP and population)

PUBLICATION QUALITY

Figure 23 depicts the quality of publications in the primary areas of specialisation relevant to the High-tech Industrialisation domain. The size of each bubble indicates the number of articles published for 2011 to 2015 in the given area of specialisation. The publications relevant to this domain are generally of higher quality in chemistry, biochemistry, energy, physics and biochemical engineering, and less so in engineering, materials science, mathematics, decision science and computer science. However, the degree of specialisation in these areas is relatively low. There is a greater degree of specialisation in the environmental and agricultural disciplines, where the quality of the publications is also relatively high.

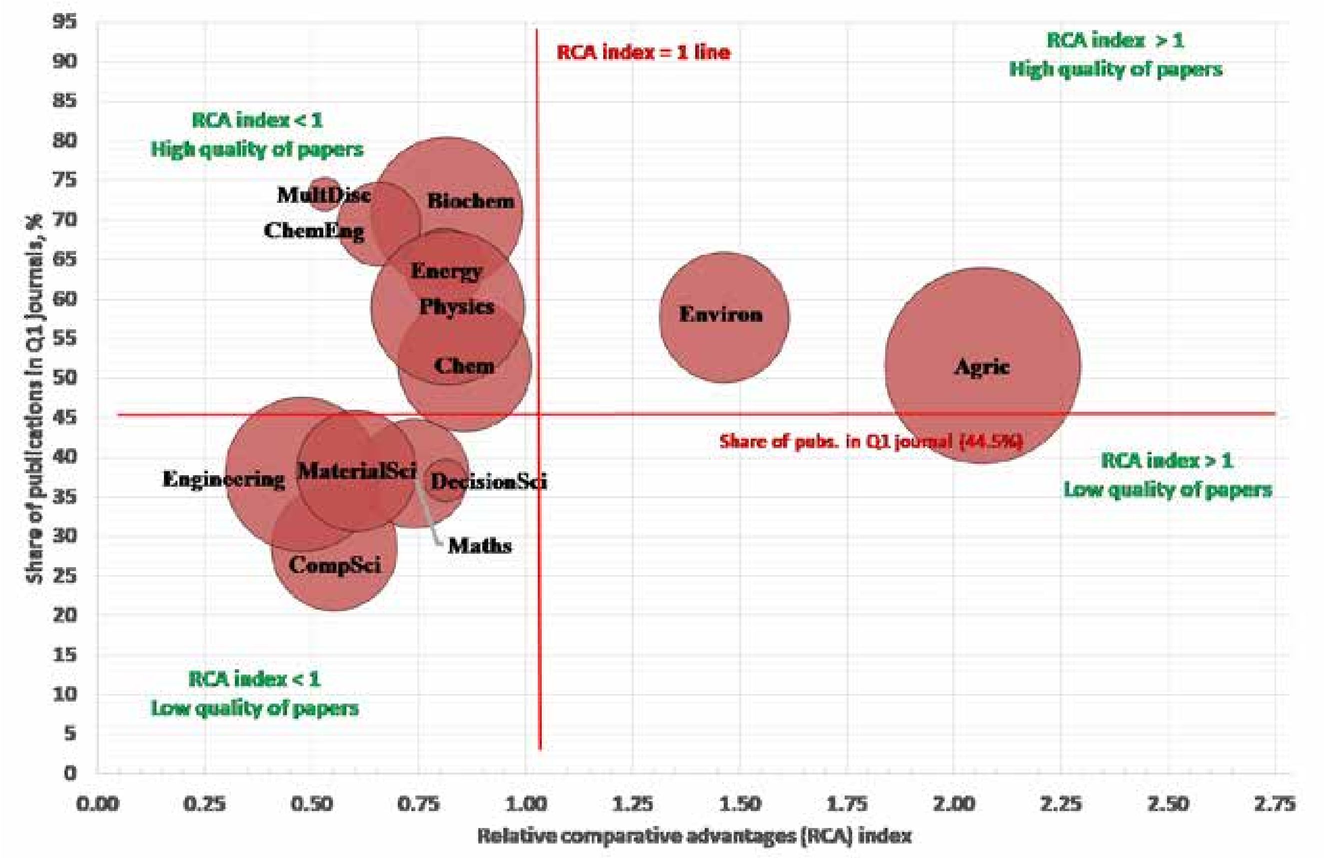

Figure 23: Quality of publications relevant to the High-tech Industrialisation domain

RECOMMENDATIONS

Three STI thrusts for the High-tech Industrialisation domain were identified and elaborated on during SAForSTI. Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F. (The thrusts are numbered HT1, HT3 and HT4, to facilitate references to background documentation. HT2 has been incorporated into a different domain.)

HT1: ENABLING SMALL BUSINESS TO ADOPT HIGH TECH

This thrust targets a number of enabling factors to assist small businesses to enter the high-tech market and to use technology to enable small business growth. It addresses the need to increase the current low number of successful and sustainable high-tech start-ups, their lack of access to intellectual property and technology, and the difficulty of doing business due to problems with logistics, financial systems and regulatory barriers.

The thrust aims to establish support systems for start-ups that are all freely available and accessible. Examples include cloud services for shared administration, and improved online business services to deal with business registration, tax and regulation issues. Government-owned intellectual property could be made available for alternative exploitation and a venture capital fund established through public-private partnerships. The Public Finance Management Act needs to be adjusted to promote public procurement from SMMEs.

A generic approach is inappropriate, and implementation plans will have to be sector-specific, as their needs and ecosystems will be different. Access to and adoption of high-tech will be crucial. The provision of independent advice, as a service, may reduce the risk for small businesses.

HT3: NEW THINKING FOR NEW INDUSTRIES

This thrust addresses the development of new high-tech sectors for the country, given South Africa's poor record in new industry creation and reliance on legacy industries. Possible examples include space technology, green chemistry, cybersecurity, biometric security, additive manufacturing and autonomous mining vehicles.

The outcome of this thrust will be a transition to a knowledge-based and greener/circular economy, while establishing a stronger presence for South Africa in the global high-tech space. The creation of more start-ups will contribute, through a multiplying effect, to the stimulation of supply chains, and to growth and employment in highly-skilled, high-paying jobs in the high-tech and green sectors. These new businesses will contribute towards export of medium to high-tech goods and services, broadening South Africa's current exports.

Interventions include research to identify new scientific and technological areas for development; the acceleration of high-tech enterprise development and support through the harmonisation of technological innovation and commercialisation instruments, and the acquisition of foreign technologies for local adaptation and diffusion where appropriate; the creation of a pool of appropriately skilled and highly trained workers based on an assessment of the skills capacity and skills needed in these new industries; a national network of high-tech incubators and accelerators; funding for development and commercialisation of technologies, and start-up capital; and new policies to regulate the digital, green and circular economies.

HT4: NEW THINKING FOR OLD INDUSTRIES

This thrust addresses the need to rethink "old" industries by seeking novel combinations of old, new and advanced technologies and knowledge for improved competitiveness and efficiencies in existing and distressed industries (the current industrial base). The intent is to drive current industries into the future by adopting newer technologies and by becoming more digitally competent. Some industries are likely to disappear over the years due to factors such as deindustrialisation and low competitiveness. There will be job losses while industries jump to the next wave of innovation to stay competitive and become more resilient, but this will be offset by improved productivity, potentially enabling growth in currently distressed sectors. Workers will have to be reskilled as companies upgrade their technologies if jobs are to be saved.

A comprehensive technology audit of currently distressed business sectors will be needed to implement this thrust. Productivity-enhancing technologies to improve competitiveness will be identified and procured through technology scouting, and deployed in prioritised businesses. The establishment of an industry extension programme is required, with funding to access foreign technologies for local adaptation and diffusion; create a new product and services development programme; and establish a programme for upgrading and improving skills.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

The High-tech Industrialisation domain addresses the need to assist small businesses to enter the high-tech market and to use technology to enable small business growth, which the NDP considers key to job creation and employment growth. Likewise, the development of new high-tech sectors and the transformation of existing and distressed industries are both important components in improving the competitiveness and efficiency of the country's industries, by adopting novel combinations of old, new and advanced technologies. Although there is evidence of a fast-growing scientific research emphasis relevant to this domain, particularly in the last three years, South Africa's research output is still very low and there are key deficiencies in research capacity, especially in the areas of engineering, materials science, computer science, mathematics and the decision sciences. Significant investment and support will be required if this to change.

Some specific policy considerations are as follows:

- Establishment of a national network of high-technology business incubators and accelerators.
- The harmonisation of instruments to foster technological innovation with those that support commercialisation.
- Greater support of the existing Technology Localisation Programme to enable a massification of the programme throughout South Africa, and its expansion to include new instruments and services, such as the technology auditing of distressed industries with a view to their rejuvenation.
- Revisit small business regulatory requirements with a view to the relaxation of requirements (including of labour laws) for start-ups and SMMEs.

CHAPTER

9

ICTs AND SMART SYSTEM

INTRODUCTION

OVERVIEW

The present chapter sets out the results of SAForSTI with respect to the ICT domain and includes technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data analytics, blockchain, robotics, cloud computing, grid computing, modelling simulation, gaming and quantum computing. AI, for example, offers unique opportunities to improve human lives and to address major societal challenges, but its full impact remains difficult to appraise beyond that intelligent devices and systems are likely to drive irreversible changes in our society. Many jobs that are task-based or require simple decisions will be carried out using AI instead of people.

ISSUES AND DRIVERS

Preparing for a changed society in the 4IR featured strongly in the foresight deliberations, with discussions on the types of education and training that would be required, given that South Africa has fallen behind in terms of its ICT infrastructure and access. The opinion was expressed that the digital divide will continue and possibly worsen by 2030. The point was made during stakeholder interviews that education will need to focus on areas in which humans have a competitive advantage over AI, e.g. interpersonal skills and team collaboration. People will need to be adaptable and to change their professions rapidly as their circumstances and environments change.

Data science is a new and important cross-cutting platform for socio-economic development as well as for fundamental research. The ability to create, analyse and make use of very large data sets is one of the drivers of new mathematics, and is also having a large influence on research efforts, for example those related to the Square Kilometre Array. One stakeholder stated –

> *We need people who can make data to talk to the people who can work the data and produce results. We need to invest in developing people with this expertise. Twenty years ago, IT and tech transfer specialists were needed. However, now these have become basic enablers, part of the infrastructure, and the need is for data specialists. We have potential access to massive data sets, but we do not have the capacity to analyse these and derive meaningful information. So, we need to build our data science capabilities. The potential is enormous, but it needs intentional investment.*
> *– Stakeholder interview (5 September 2018).*

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 24 indicates that there is growing scientific emphasis on the ICT domain in South Africa. However, the number of publications and South Africa's share of global scientific output (about 0,6%) are still very low, as is South Africa's global position (45th place, with 16 400 publications).

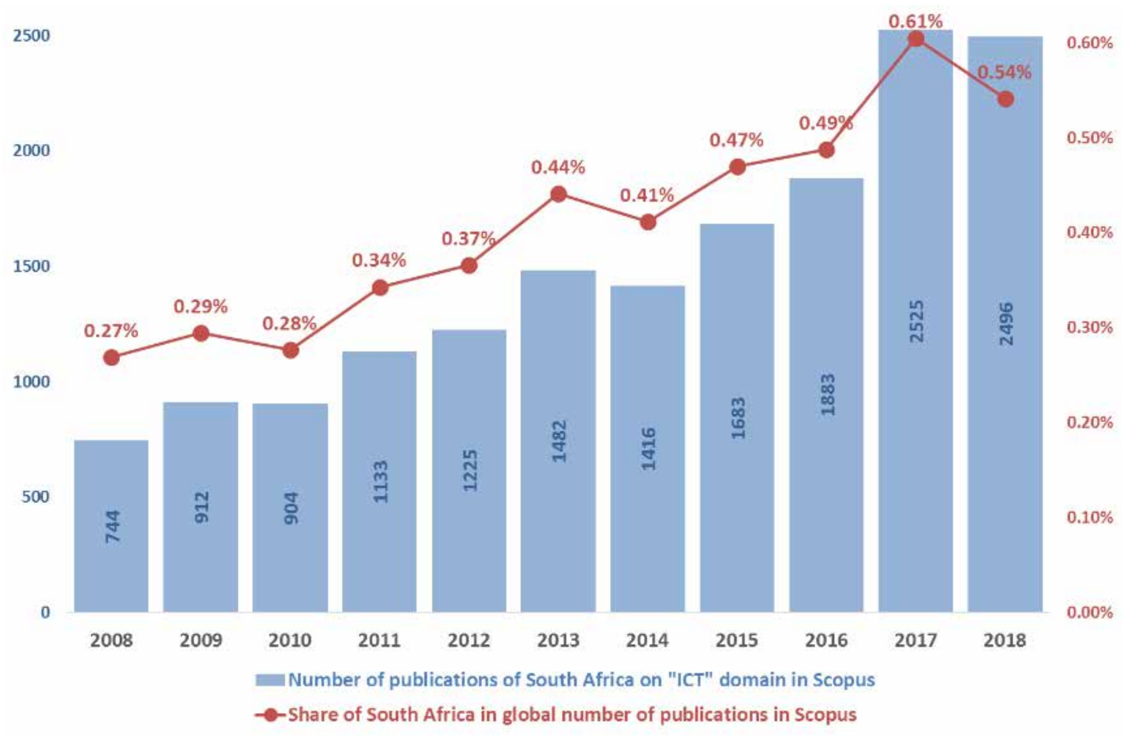

Figure 24: Publication activity related to the ICT domain

Figure 25 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population. The BRICS countries are highlighted. Among the BRICS countries, South Africa produced the highest number of publications related to the ICT domain, both per GDP and per size of population.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Tunisia	17.1	40.0	428.0
Malaysia	51.2	314.7	162.7
South Africa	56.7	348.9	162.6
Iran	54.3	454.0	119.6
Poland	51.4	526.5	97.6
Hungary	13.3	139.8	95.2
Spain	120.9	1314.3	92.0
Morocco	10.0	109.7	91.2
India	230.1	2650.7	86.8
UK	216.0	2637.9	81.9
Canada	134.8	1647.1	81.8
Netherlands	66.8	830.6	80.4
Australia	103.1	1323.4	77.9
South Korea	118.5	1530.8	77.4
Algeria	12.7	167.6	75.8
Italy	142.6	1943.8	73.4
Egypt	16.7	235.4	71.0
Switzerland	47.9	679.0	70.5
China	852.2	12237.7	69.6
France	173.7	2582.5	67.3
Germany	234.3	3693.2	63.4
Pakistan	18.4	305.0	60.3
US	750.5	19485.4	38.5
Japan	185.5	4872.4	38.1
Chile	10.1	277.1	36.5
Russia	55.6	1578.4	35.2
Colombia	10.7	314.5	34.0
Brazil	66.1	2053.6	32.2

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Switzerland	47.9	8.5	563.5
Australia	103.1	24.6	419.1
Netherlands	66.8	17.1	390.6
Canada	134.8	36.7	367.3
UK	216.0	66.0	327.3
Germany	234.3	82.7	283.3
Spain	120.9	46.6	259.4
France	173.7	67.1	258.9
Italy	142.6	60.5	235.7
US	750.5	325.1	230.9
South Korea	118.5	51.5	230.1
Malaysia	51.2	31.6	161.9
Tunisia	17.1	11.5	148.3
Japan	185.5	126.8	146.3
Hungary	13.3	9.8	135.9
Poland	51.4	38.0	135.3
South Africa	56.7	56.7	100.0
Iran	54.3	81.2	66.9
China	852.2	1386.4	61.5
Chile	10.1	18.1	55.9
Russia	55.6	144.5	38.5
Brazil	66.1	209.3	31.6
Algeria	12.7	41.3	30.7
Morocco	10.0	35.7	28.0
Colombia	10.7	49.1	21.8
India	230.1	1339.2	17.2
Egypt	16.7	97.6	17.1
Pakistan	18.4	197.0	9.3

Population (2017)

Figure 25: Number of publications in the ICT domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 26 depicts the quality of publications in the primary areas of specialisation relevant to the ICT domain. The size of each bubble indicates the number of articles published for the period 2011 to 2015 in the given area of specialisation.

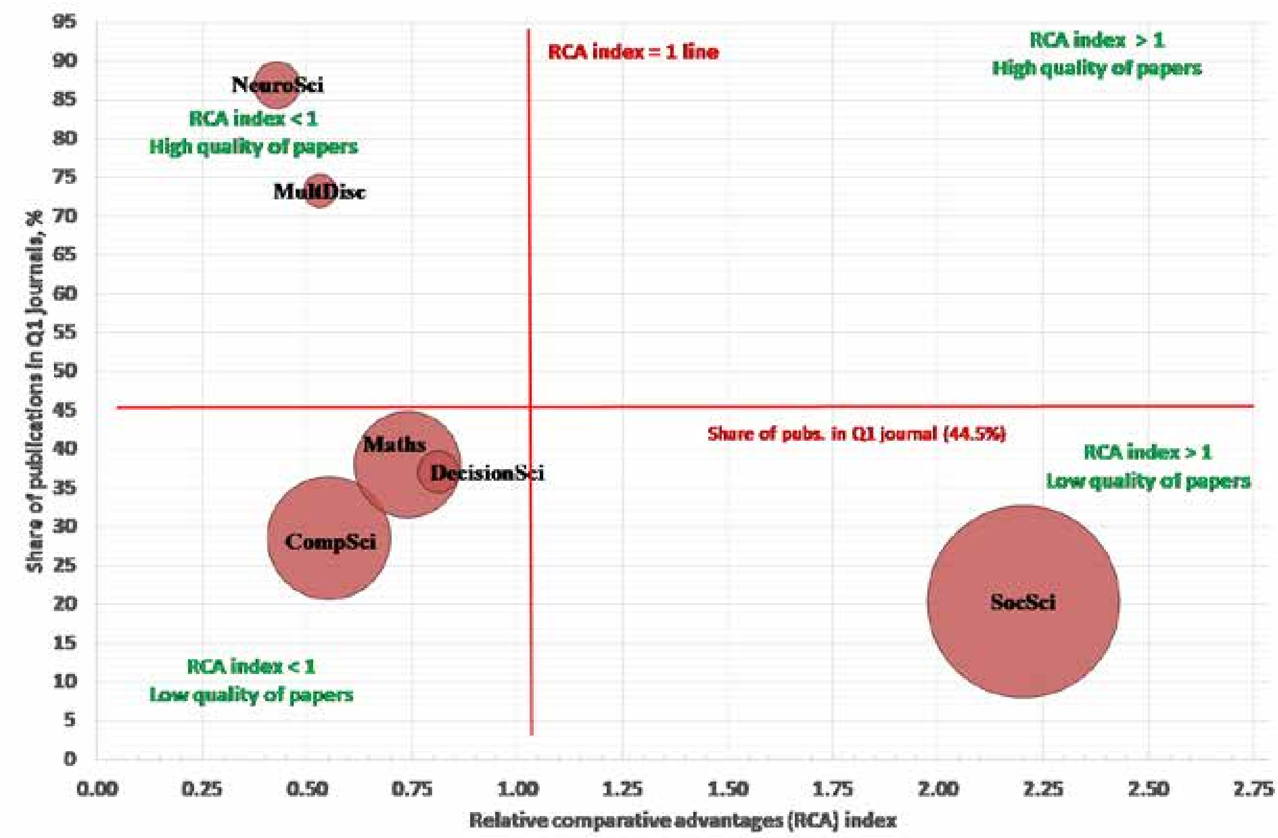

Figure 26: Quality of publications relevant to the ICT domain

It is of concern that there are no disciplines relevant to the ICT domain for which the degree of specialisation and the quality of publications are both high. There is the capability to produce high-quality research outputs in the neurosciences, but the degree of specialisation is relatively low. On the other hand, the degree of specialisation in the social sciences is relatively high, but the quality of the research outputs is relatively low.

RECOMMENDATIONS

Four STI thrusts for the ICT domain were identified and elaborated on during SAForSTI: Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

IT1: CHECKS AND BALANCES FOR A DIGITAL FUTURE

This thrust addresses some of the threats and opportunities that can be taken advantage of, related to ICTs such as social media, big data and artificial intelligence (AI), through developing processes, policies, information, technology solutions and/or legislation. The full impact of AI on society is unknown, but moral and ethical dilemmas related to AI are likely to increase. If AI is used without ethical guidelines, this may lead to widening social divides, with algorithms generating misinformation that fuels mistrust and entrenches divergent positions. The regulatory environment needs to be examined to ensure that there are checks and balances in place for the digital future. A more secure cyber-environment will also promote business and investment, leading indirectly to increased employment and reduced poverty.

The outputs of this thrust will result in a better understanding of the moral and ethical dilemmas presented by new technologies, developed from a local perspective in terms of governance and policy interventions, as well as legal frameworks appropriate for the South African context. New technologies and procedures to address security issues and cybercrime will be identified and defined, including new technologies to support personal choice rather than, for example, media algorithms. Information products will be produced to inform people of moral and ethical challenges, risks and the mechanisms to mitigate risks. The proposed frameworks will ensure that AI contributes to the public benefit and does not increase social fragmentation. All the implemented policies, processes and laws will be supported by monitoring mechanisms.

IT2: ICT INFRASTRUCTURE AND INTERNET ACCESS

This thrust aims to provide affordable and easily accessible broadband Internet access for all, and to facilitate the development of innovative 4IR-based applications and services. It addresses the urgent need to reduce the high cost of ICT infrastructure and resolve the current uneven ICT infrastructure rollout, resulting in the ongoing rural/urban digital divide. The lack of digital skills, particularly in rural and marginalised areas, requires attention.

One of the greatest challenges will be the effective coordination of research efforts and the mobilisation of relevant players (from national to local government to industry, NGOs and communities). Industry partnerships with appropriate industries are needed, with global standards and regulatory bodies to guarantee the interoperability and compatibility of ICT systems. Sufficient radio spectrum needs to be allocated, including tools for spectrum sharing. The outcome will be a seamless ICT infrastructure that deploys affordable broadband Internet access to all, closes the digital divide and grows South Africa's GDP. This will improve communication and information exchange between ICT ecosystem stakeholders (government, industry and society) and see the emergence of a growing SMME sector of network and ICT service providers.

An abundance of digital skills is likely to emerge in all relevant areas. An increased number of ICT-focused SMMEs will create more job opportunities and provide value-added services. R&D and test-bed capabilities will foster the rapid development and deployment of ICT and networking technologies countrywide. The move from personalised to machine-type communication will result in radically new communication networks, data collection, data analytics algorithms and architectures, including seamless and secure access. South Africa will have developed adequate hardware and software skills to satisfy local needs, with the possibility of growing regional and global exports.

IT3: BIG DATA, DATA ANALYTICS AND DECISION SUPPORT

This thrust focuses on the development of skills and systems to enable decision support in government and the private sector. This will enable evidence-based policy decisions on resource management through the utilisation, processing and contextualisation of data from ground-based and space-based (satellite) sensor networks. It addresses the development of critical data analytic skills, as well as the development and deployment of sensor networks (ground and space).

Government policy and regulatory decisions on resource management have spatial contexts that are often not evidence-based, or are misdirected because the data has not been correctly interpreted. This can result in targeted interventions that are misdirected or inappropriate. This is exacerbated by the lack of effective monitoring and evaluation systems.

The outcomes of this thrust will include a government decision-support platform for strategic spatial resource management, using both ground and space-based sensor networks. Enhanced data science and analytics programmes will be established at universities and research institutions to meet local (and possibly global) needs for big data and data analytics. The creation of a national data science centre that could provide critical big data and data analytics services to state agencies should be considered.

IT4: SMART AND SUSTAINABLE MUNICIPAL SERVICE DELIVERY

To date, municipalities have largely been excluded from innovation decision-making processes, yet they have an important leadership role to play in the innovation ecosystem. This thrust proposes the use of ICT and smart systems to create smart cities through the delivery of a range of smart services such as e-government, e-health, smart transport systems and resource management. The outcome of this thrust will see the improved financial sustainability of municipalities. To realise this vision requires a coherent and integrated strategy to leverage the technology investments that need to be made.

Since 1994, municipalities have faced service delivery challenges that are attributed to poor financial management, inadequate human and institutional capacity, overstretched infrastructure and weak governance systems. Local government service delivery failures cannot be remedied by increased investment alone. A fundamental shift in institutional arrangements is needed if municipalities are to create smart and sustainable developmental agendas. Municipalities also need to contribute to making the circular economy a reality. Intensified research efforts are needed to address waste reduction and to find alternatives to landfills, as not doing so will result in polluted and unliveable cities.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

The importance of reskilling and training people in ICTs and smart systems was an underlying theme in all the thrusts, and particularly so because of the likely job losses that will result from increased automation and the introduction of smart systems in most areas that make up our society. New ICTs will, however, bring forth many benefits across a broad scope of areas, in healthcare, resource management, public service delivery and education.

Although there is growing scientific emphasis on the ICT domain in South Africa, the publication output is still very low (0,06% of the global output) as is the quality of the research outputs for most of the relevant areas of research. A policy of strategic investment in relevant research capacity for the ICT domain should be considered.

Some specific policy considerations are as follows:

- Establish enabling policy and a regulatory framework to ensure digital interoperability and quality of service, and a level playing field for healthy competition.
- Develop a national open data policy to ensure open access and data sharing among government departments, state-owned enterprises, the private sector and civil society, and to stimulate the use of open access data and the realisation of added value from such use.
- Support research into, and the development of policies to address the impact of new ICTs (such as social media technologies) on South African society, including for example, social interactions, business behaviour, political systems, and trust. The policies should also address aspects such as informing people of the moral and ethical challenges involved in certain ICTs, and the associated risks and mechanisms to mitigate those risks. They should also address the monitoring of the level of public knowledge, the tone of public discourse, the roll-out of checks and balances, and the success of strategies to reduce the harmful impacts of ICTs.

CHAPTER

10

NUTRITION SECURITY

INTRODUCTION

OVERVIEW

The Nutrition Security domain looks at ways in which agriculture, and particularly precision agriculture, can contribute to increasing nutrition security in the country, as well as addressing the impacts of climate change.

> *South Africa has a rich variety of flora and fauna. Agriculture is the foundation of the South African economy, and of our food security, and yet it does not have the place it should have in our order of priorities. If one steps back and looks at South Africa's agricultural production, the picture is not rosy. Much is needed to improve.*
> *–Stakeholder interview (10 October 2018).*

ISSUES AND DRIVERS

Good nutrition is essential for lifting people out of poverty and building healthy populations. Good nutrition is not an option for poor South Africans. Malnutrition and stunting affect 25% of the under-fives in this country, permanently compromising their cognitive and physical development, and amplifying current socio-economic inequalities. At the same time, there is an upward trend in overweight/obese adults and children, with more than 60% of South African women affected. Integrated, transdisciplinary solutions are needed to address both nutrition and agriculture reform in the light of climate change. The opportunity should be taken for poor rural communities to provide local nutritious foods for themselves and others, creating jobs and better health. A nutrient-rich diet relies on food diversity, but many foods spoil easily and the emphasis needs to move towards decreasing post-harvest spoilage.

> *Those in the rural areas should be far more involved in the production of food products from the raw materials. This is a route to empowerment. If people eat well, then they can work hard and be productive. So, nutrition is critical. It is very important to provide access to highly nutritious products.*
> *–Stakeholder interview (4 September 2018)*

Precision agriculture has the potential of taking South Africa's agricultural sector (possibly the most successful in Africa) to the next level. The growing pressure on South Africa's limited arable land, and increased urbanisation, means that urban precision agriculture should also receive attention. Farm management should be developed to optimise return on inputs and investment, and preserve scarce resources based on the convergence of digital technologies. Precision agriculture can improve yields, reduce waste and pollution, reduce the land area required for agriculture, and reduce water and energy demands.

> *How can the science councils engage with the agricultural sector? There are significant opportunities for developing technologies for agroprocessing. There is also the possibility of some job creation. A priority is to make the land more productive. This can be pursued by providing access to technology that improves the productivity of the land. – Stakeholder interview (4 September 2018)*

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 27 indicates that there is growing scientific emphasis in areas related to the Nutrition Security domain, with gradual growth in the number of publications from 1 458 to 3 000. South Africa's share of the global scientific output shows growth during this period (0,91% to 1,21%). The country is placed 25th globally, with 23 900 publications.

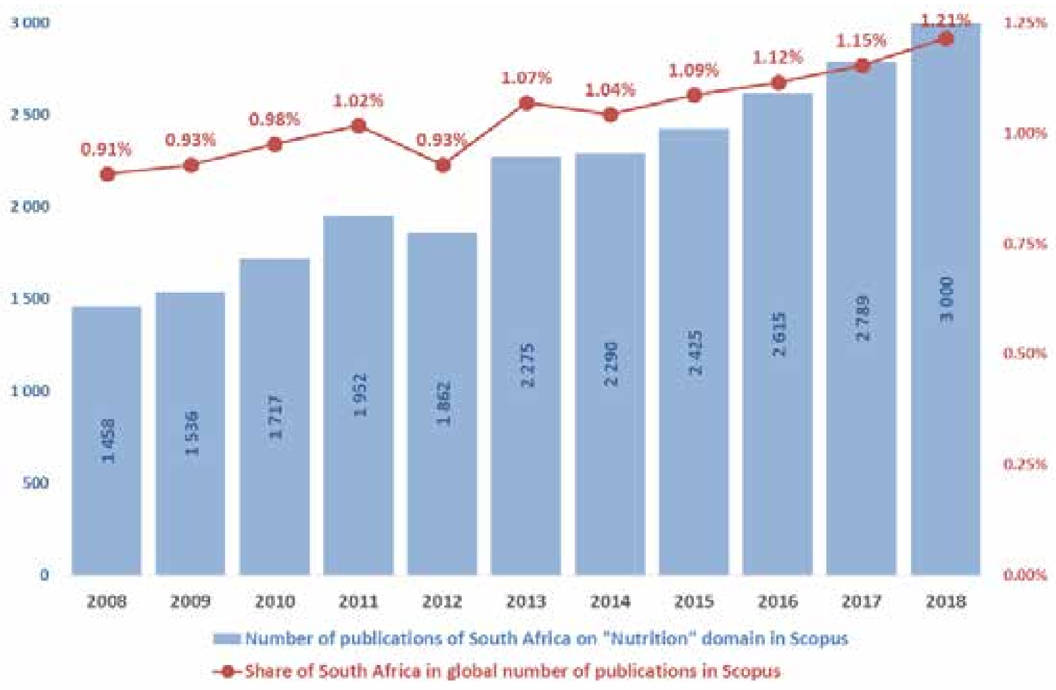

Figure 27: Publication activity related to the Nutrition Security domain

Figure 28 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population. Of the BRICS countries, South Africa produced the second highest number of publications related to Nutrition Security, measured in terms of both GDP and population size.

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
New Zealand	22	204,1	107,8
Iran	46,5	454,0	102,4
Czech Republic	21,2	215,9	98,2
Portugal	21,3	219,3	97,1
Denmark	30	329,9	90,9
Poland	42,5	526,5	80,7
Spain	94,2	1 314,3	71,7
Australia	92,9	1 323,4	70,2
South Africa	23,9	348,9	68,5
Belgium	32	494,8	64,7
Sweden	33,3	535,6	62,2
Netherlands	49,2	830,6	59,2
Brazil	119,1	2 053,6	58,0
Canada	91,2	1 647,1	55,4
UK	140,7	2 637,9	53,3
Turkey	44,8	851,5	52,6
Norway	20,9	399,5	52,3
Italy	95,3	1 943,8	49,0
India	126,2	2 650,7	47,6
Switzerland	32,2	679,0	47,4
South Korea	61	1 530,8	39,8
Argentinia	22,6	637,4	35,5
France	86,4	2 582,5	33,5
Germany	114,9	3 693,2	31,1
Mexico	33,1	1 150,9	28,8
US	533,2	19 485,4	27,4
China	265,8	12 237,7	21,7
Japan	97,6	4 872,4	20,0
Russia	25,3	1 578,4	16,0

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Denmark	30	5.8	517.2
New Zealand	22	4.8	458.3
Norway	20.9	5.3	394.3
Switzerland	32.2	8.5	378.8
Australia	92.9	24.6	377.6
Sweden	33.3	10.1	329.7
Netherlands	49.2	17.1	287.7
Belgium	32	11.4	280.7
Canada	91.2	36.7	248.5
UK	140.7	66	213.2
Portugal	21.3	10.3	206.8
Spain	94.2	46.6	202.1
Czech Republic	21.2	10.6	200.0
US	533.2	325.1	164.0
Italy	95.3	60.5	157.5
Germany	114.9	82.7	138.9
France	86.4	67.1	128.8
South Korea	61	51.5	118.4
Poland	42.5	38	111.8
Japan	97.6	126.8	77.0
Iran	46.5	81.2	57.3
Brazil	119.1	209.3	56.9
Turkey	44.8	80.7	55.5
Argentinia	22.6	44.3	51.0
South Africa	23.9	56.7	42.2
Mexico	33.1	129.2	25.6
China	265.8	1386.4	19.2
Russia	25.3	144.5	17.5
India	126.2	1339.2	9.4

Population (2017)

Figure 28: Number of publications relevant to the Nutrition Security domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 29 depicts the quality of publications in the primary areas of specialisation relevant to the Nutrition Security domain. The size of each bubble indicates the number of articles published for 2011 to 2015 in the given area of specialisation.

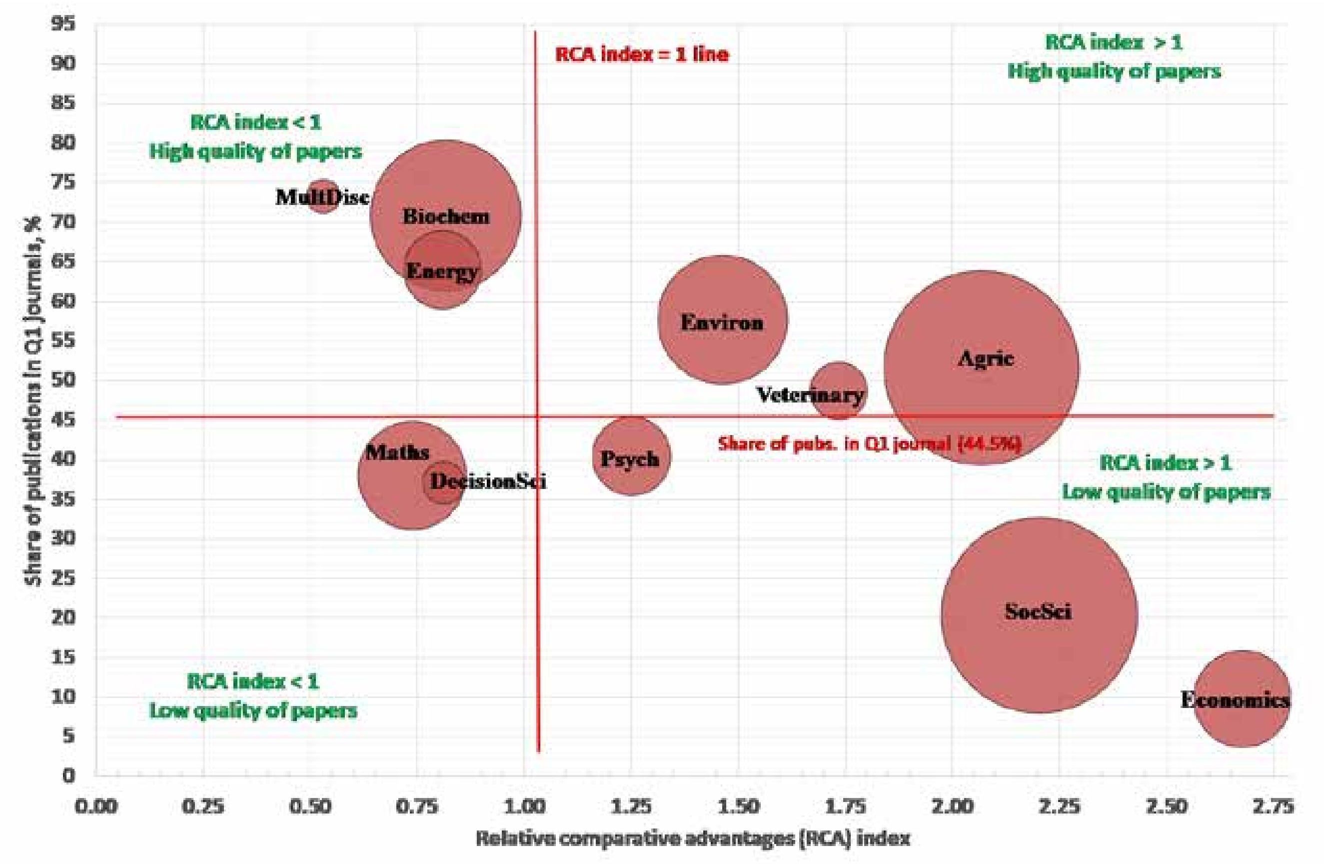

Figure 29: Quality of publications relevant to the Nutrition Security domain

Disciplines relevant to the Nutrition Security domain with a relatively high quality of research outputs include biochemistry, energy, and the environmental, veterinary and agricultural sciences. However, the degree of specialisation in the country is low for biochemistry and energy. On the other hand, there is a high degree of specialisation in the social sciences and economics, but the quality of the research outputs is relatively low.

RECOMMENDATIONS

Four STI thrusts for the Nutrition Security domain were identified and elaborated on during SAForSTI. Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

NU1: ZERO-IMPACT AGRICULTURE

This thrust closes the water, energy, food and social nexus. Agriculture goes off the water and energy grids by using dispersed, small but intensive production facilities in both rural and urban areas to produce balanced animal and plant products for local consumption. The risks of climate change are mediated through the use of controlled environments, allowing higher yields, healthier and diverse crops and livestock production at lower resource cost and use (nitrogen, energy, water requirements). A "for the people by the people" approach empowers small, local producers to produce high-value crops on small patches of land for local communities.

The aim is to ensure the sustainable production of food under extreme and changing climatic conditions across South Africa, in both rural and urban areas. Through the use of technology, small and remote (rural) producers can increase their productivity. The thrust addresses the challenges presented by climate change and water scarcity, the need for nutrition diversity and improvement, as well as the lack of social enterprises that can contribute to, and benefit from, the circular economy. South Africa's carbon, nitrogen, water and energy footprints can be reduced. As a starting point, the concept of farming needs to be transformed to that of owning a small agribusiness so that there is more appeal for a younger generation not generally drawn to farming as a career or business choice. A transformational mind shift needs to occur in communities, to one of participation and self-reliance.

NU2: USE AND ACCEPTANCE OF MODERN BIOTECHNOLOGY

This thrust focuses on the opportunities presented by researching genetically modified and genome-edited organisms (crops, livestock, microbes), and developing local research capacity in genomics and phenomics technologies. These can enhance and secure agricultural productivity across the sector through improved responses to biotic and abiotic stresses, and traits aiding in improvements in nutritional values and production outputs. With the negative impacts of climate change on agribusiness and the need to address nutritional deficiencies more effectively, these biotechnologies may provide the solution to feeding a growing population, while bringing down production costs.

Education is needed on genetically modified (GM) foods (where foreign DNA is introduced) versus genome-edited (where the DNA is manipulated, but no foreign DNA is introduced), as any laboratory-based research is currently classified as being GM in South Africa. This perception and the current requirement to treat "everything as GM unless otherwise indicated", deters local businesses from using such biotechnologies.

This is preventing South Africa from building expertise in the area, which may result in the country having to import these technologies at high cost in the future.

The outcomes of this thrust will be more resilient crops and livestock, better adapted to changes in climate and to threats caused by pests, pathogens and diseases. Agricultural products will provide enhanced nutrition and more affordable and healthier foods, leading to reduced levels of food and nutrition insecurity. The outcome will be a more viable and sustainable smallholder agribusiness sector that offers increased employment opportunities.

NU3: PERSONALISED INFORMATION FOR HEALTHY NUTRITION FOR ALL

This thrust addresses the use and application of ICTs to provide personalised information on nutrition and the nutritional status of all groups, but particularly for vulnerable groups, e.g. mothers, caregivers and young children. The aim is to enhance nutrition security by improving health and nutrition outcomes and providing information on levels of malnutrition in the country. Given the high levels of malnutrition, stunted growth, obesity (due to poor nutrition), micronutrient deficiencies and accompanying non-communicable diseases it is important to have access to personalised data so that problems can be better managed.

Access to accurate and more detailed data will result in better decision making and improved, better-targeted policies on nutrition. This should result in reduced national expenditures on health as an outcome of healthier choices, especially related to the cost of management of non-communicable diseases and malnutrition-related disease.

NU4: PRECISION AND BIG DATA IN AGRIBUSINESSES

This thrust deals with streamlining agribusiness across the value chain through the use of ICT, communication systems and other high-throughput technologies. It allows the tracking of produce from the field to the plate, with information flows through the whole value chain. New cultivars can be developed using genomics and phenomics, based on big data and data analytics using data captured during production by means of satellite and other precision technologies.

Big data will provide information on a number of critical dimensions, e.g. water availability and what should be planted where and when; nutrition diversity through better resources and knowledge; pest, disease, and pathogen management and tracking; alternative production systems to increase soil health and to lower nitrogen and other requirements; soil improvement through better land management practices; optimised transport and food distribution based on improved access to current and relevant information; lower production costs and less wastage of produce; better water, soil and resource conservation.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

South Africa's research output shows some strengths and a growing scientific emphasis on the Nutrition Security domain, producing the second highest number of publications per GDP and per population size of all the BRICS countries. However, more investment is needed to improve the degree of specialisation in disciplines relevant to the domain, such as biochemistry and energy, and to improve the quality of research outputs in disciplines such as the social sciences.

Some specific policy considerations are as follows:

- Adjust relevant policies to enable and encourage individuals to build sustainable agri-businesses that drive and contribute to their local economies.
- Update existing policies to regulate genetically modified products and processes more effectively, enabling a greater use and acceptance of modern biotechnology.
- Develop policy and a regulatory framework for the use of personalised nutritional status information. This should make provision for new technologies for measuring the nutritional status of a population.

CHAPTER

11

WATER SECURITY

INTRODUCTION

OVERVIEW

The Water Security STI domain focuses on reducing water wastage, water pollution and water usage, with particular emphasis on the implications for rural areas.

> *Water recycling is very important for South Africa, but we lag behind. Most of our expertise is in the iron and steel, and mining industries ... The water-saving technologies that we need are different from those in the developing world and should be tailored to the African environment. –Stakeholder interview (2 August 2018)*

South Africa's Water Research, Development, and Innovation (RDI) Roadmap (2015-2025) provides a structured framework to focus the contribution of RDI activity to the implementation of national policy, strategy and planning in water resource management in South Africa. The National Water Research, Development and Deployment Programme focused on the delivery of at least one breakthrough technology every five years; increasing the number of SMMEs operating in the water sector; increasing access to water for rural communities, and providing sanitation for all in a sustainable manner. However, South Africa is still faced with massive challenges in respect of water efficiency and water management. Neglecting water issues runs the risk of imposing serious negative impacts on economies, livelihoods and populations with potentially catastrophic and extremely costly results. Unsustainable management of water and other natural resources can cause severe damage to economies and society, reversing many poverty reduction, job creation and hard-won development gains.

ISSUES AND DRIVERS

Equitable access to water is a basic human right, yet marginalised and rural communities often do not have access to clean water or related technologies. With climate models predicting that South Africa will become drier, increasing water shortages will be a growing trend over the coming decades. Water will become more expensive.

> *The energy-water nexus is important – the water-energy-food nexus is even more important. This links to climate change and the impact that will have on these areas. There are niche areas in the water-energy-food nexus where we could make a significant contribution. –Stakeholder interview (5 September 2018).*

Ageing and poorly maintained water infrastructure and the failure to invest in water management not only represents missed opportunities but may also impede economic growth and job creation. This is particularly relevant given that the largest portion of South Africa's energy supply relies on water for generation

Proactive, innovative, interdisciplinary, environmentally sustainable solutions are needed, giving attention to, among other aspects, demand control, land management, wastewater treatment, local level approaches to supply and management, the role of data science, and social change management to effect sustainable behavioural changes.

THE CURRENT STATUS OF THE DOMAIN

RESEARCH CAPACITY AND KNOWLEDGE GENERATION

Figure 30 depicts the contribution by South African researchers to the global process of knowledge generation related to water security during the period 2008 to 2018. There has been steady growth in scientific emphasis in South Africa on water security-related topics, particularly from 2016 onwards. The number of publications has been growing slowly but steadily, as has South Africa's share in the global scientific output related to this domain (23rd, with 6 600 publications).

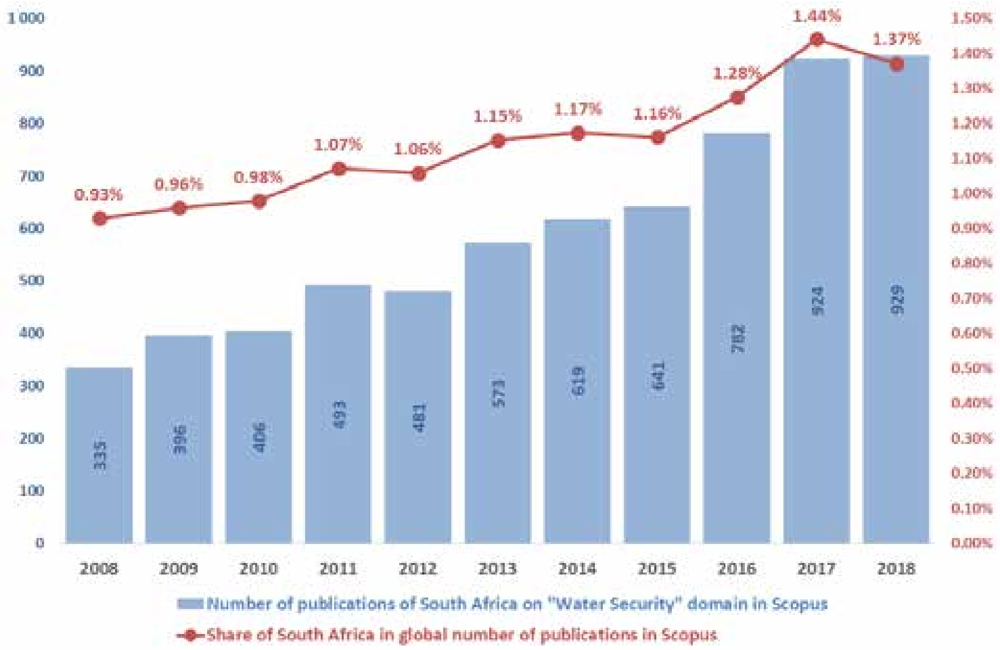

Figure 30: Publication activity related to the Water Security domain

Figure 31 depicts publication activity relative to other countries during the period 2008 to 2018. The number of publications produced has been normalised according to both GDP and population. The BRICS countries are highlighted. Among the BRICS countries, South Africa produced the highest number of publications related to the Water Security domain, both per GDP and per size of population

Country	Publ ('000)	GDP (USDbn)	Publ/GDP
Iran	15.6	454.0	34.4
Portugal	6.1	219.3	27.8
Malaysia	7.7	314.7	24.5
South Africa	6.6	348.9	18.9
Australia	24.9	1323.4	18.8
Spain	21.3	1314.3	16.2
Poland	8.4	526.5	16.0
Canada	23.7	1647.1	14.4
Netherlands	11.9	830.6	14.3
Sweden	7.0	535.6	13.1
India	33.2	2650.7	12.5
Switzerland	8.3	679.0	12.2
Turkey	9.3	851.5	10.9
UK	27.8	2637.9	10.5
China	120.4	12237.7	9.8
Italy	17.6	1943.8	9.1
South Korea	12.9	1530.8	8.4
Brazil	16.9	2053.6	8.2
France	20.7	2582.5	8.0
Germany	28.0	3693.2	7.6
US	120.5	19485.4	6.2
Mexico	6.4	1150.9	5.6
Russia	8.3	1578.4	5.3
Japan	17.3	4872.4	3.6

GDP (2017)

Country	Publ ('000)	Pop (m)	Publ/Pop
Australia	24,9	24,6	101,2
Switzerland	8,3	8,5	97,6
Netherlands	11,9	17,1	69,6
Sweden	7,0	10,1	69,3
Canada	23,7	36,7	64,6
Portugal	6,1	10,3	59,2
Spain	21,3	46,6	45,7
UK	27,8	66,0	42,1
US	120,5	325,1	37,1
Germany	28,0	82,7	33,9
France	20,7	67,1	30,8
Italy	17,6	60,5	29,1
South Korea	12,9	51,5	25,0
Malaysia	7,7	31,6	24,3
Poland	8,4	38,0	22,1
Iran	15,6	81,2	19,2
Japan	17,3	126,8	13,6
South Africa	6,6	56,7	11,6
Turkey	9,3	80,7	11,5
China	120,4	1386,4	8,7
Brazil	16,9	209,3	8,1
Russia	8,3	144,5	5,7
Mexico	6,4	129,2	5,0
India	33,2	1339,2	2,5

Population (2017)

Figure 31: Number of publications relevant to the Water Security domain (normalised according to GDP and population size)

PUBLICATION QUALITY

Figure 32 depicts the quality of publications in the primary areas of specialisation relevant to the Water Security domain. The size of each bubble indicates the number of articles published for the period 2011 to 2015 in the given area of specialisation.

This analysis indicates that South Africa has significant specialised research capacity producing high-quality outputs in areas such as the environment, earth sciences, and agriculture. Other areas with high-quality research outputs include biochemistry, energy and chemistry, although the degree of specialisation is lower for these. There is also substantial specialised capacity in the social sciences and economics, but these results tend not to be published in first quartile journals.

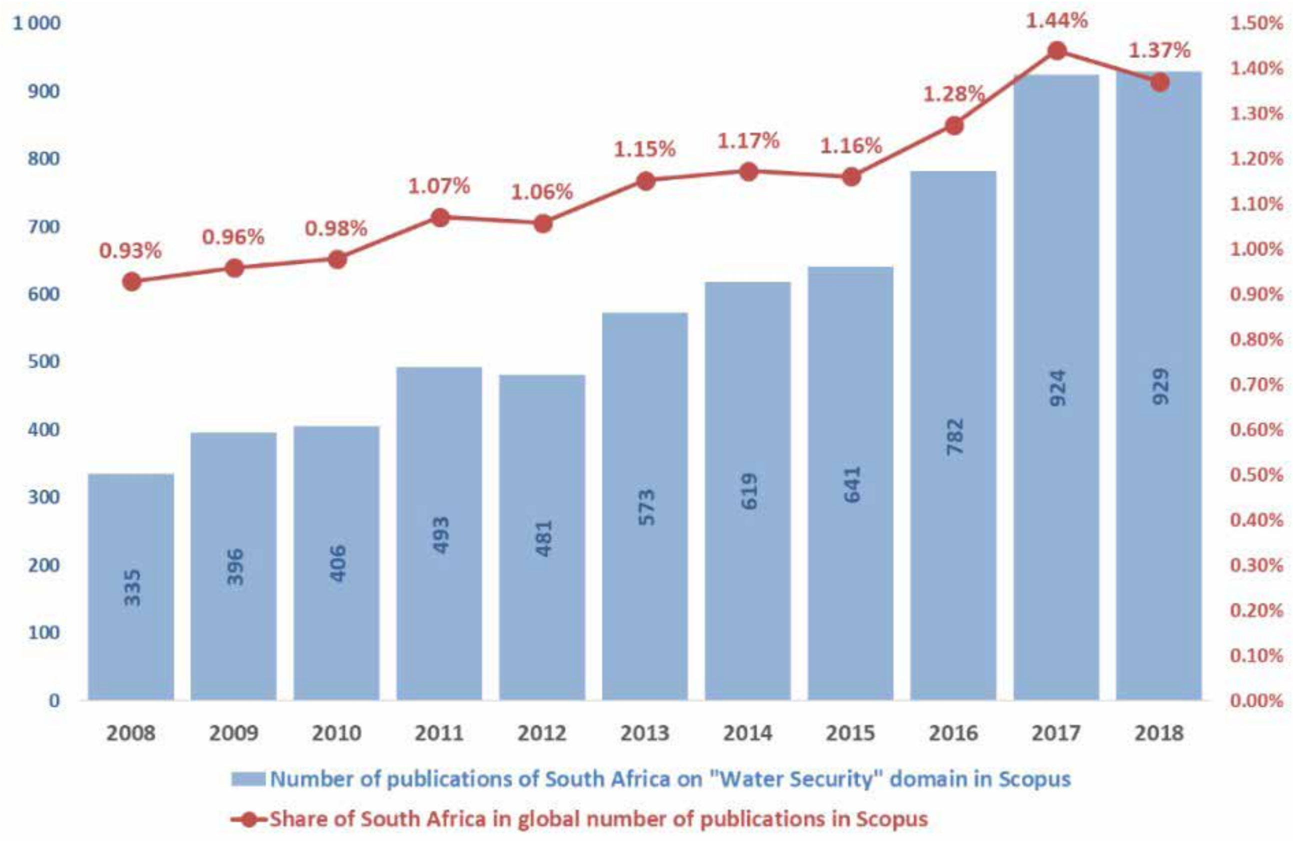

Figure 32: Quality of publications relevant to the Water Security domain

RECOMMENDATIONS

Three STI thrusts have been identified for the Water Security domain. Summary descriptions of these thrusts are set out below, with more detailed descriptions presented in Annexure F.

WA1: FUTURE-ORIENTED WATER AND SANITATION SOLUTIONS

This thrust addresses the need to develop and deploy water and sanitation solutions that are responsive to new challenges and emerging needs and opportunities, so that water security provides a basis for a thriving society and economy. Water supply will need to be driven by an integrated mix of context-appropriate sources of water at the bulk, regional and local levels. The next generation of sanitation and wastewater (urban and industrial) solutions will need to be introduced, understood and then mainstreamed (such as low or no-water use toilets, and energy and water-efficient technology). Water-sensitive designs for urban, peri-urban and rural spaces must be core to all planning, and include water and sanitation planning and implementation.

This thrust will facilitate a shift towards the use of a more diverse mix of water sources by municipalities, including the use of alternative sources of water. Such a shift will result in increased resilience during periods of drought. Infrastructure planning for new urban areas will include the consideration of wastewater and stormwater as a part of the water mix. Water capture, storage, treatment and monitoring by households and communities, based on new technologies, will be mainstreamed, thereby driving the establishment of a new water services industry. Furthermore, next-generation sanitation and wastewater solutions will be mainstreamed, such as alternative toilets (low or no-water and smart use of waste), and a reduction in the dependence on large volumes of potable water to move waste through pipe networks. Industry will be encouraged to shift to a more circular paradigm for water reuse, and to invest in appropriate technology to become more independent of water and resilient to climate change.

WA2: EMBEDDING THE WATER SECTOR IN THE 4TH INDUSTRIAL REVOLUTION

The 4IR is characterised by the enmeshing of the physical, digital and biological spheres based on technology. Cyber-physical systems are a common theme in the technologies involved. They have the potential to bring about positive change in the way water and sanitation resources and services are managed. Five areas may be identified that require attention in this regard: (a) the linking of appropriate ICTs to water resource management and service delivery; (b) increasing the data intensity with which decisions are made; (c) using cyber-physical systems to support appropriate behaviours; (d) innovative water sector monitoring and data aggregation; and (e) reskilling to operate in a data-intensive water sector environment. Building trust and relationships will be required to implement changes.

The outputs of this thrust are ICT technologies (diagnostics, robotics, artificial intelligence and distributed sensor networks) linked to water resources, supply management and service delivery through well-connected smart networks that receive timely preventative maintenance. Water sector data (enhanced by big data analytics), with strong cybersecurity, will be more widely available, up to date and accessible to inform decisions. Hydrological monitoring will be undertaken using smart, cost-effective technology. Consideration should be given to reviving South Africa's hydrological monitoring capacity as a centre.

Partnerships within the SADC and Africa should be explored for regional solution deployment and collaboration. A stronger role for the private sector should be assessed in supporting service delivery, with increased available venture capital. This will have implications for how municipalities manage their service delivery approaches and responsibilities, and may challenge the existing business models of organisations with current monopolies of selected data.

WA3: OFF-GRID AND DECENTRALISED WATER, WASTEWATER AND SANITATION SOLUTIONS

One of the key shifts that could bring the water sector closer to the opportunities of a circular economy would be the transition to off-grid and decentralised water, wastewater and sanitation solutions. Such solutions could be applied at different scales and in different markets: (a) a public market in underserviced areas and in municipalities willing to explore alternatives to the mainstream large-scale infrastructure planning approaches; and (b) the private market that supports solutions for individual households, privately owned housing estates, private companies and industry role players with water quality impacts and needs. This focus forms the basis of the Water Security thrust.

The thrust aims to deliver suites of off-grid and/or decentralised solutions that are suitable for the needs of both a private market and a public market (solutions in underserviced areas, low-cost solutions). More direct/circular water and wastewater reuse will occur on site.

Innovative business, funding and partnership models will be explored in the process of implementing off-grid and/or decentralised solutions and an ecosystem of businesses and associated manufacturing capabilities grows that is capable of handling the sale and operation of these solutions. More rapid nexus synergies can be built with food and agricultural issues on more mobile, decentralised, rapidly deployed water solutions. There is potential to massify the application of the approach to larger parts of South Africa. A set of policy and regulatory incentives supports the flourishing of off-grid and/or decentralised solutions.

This initiative offers opportunities for energy generation off the water grids, thereby contributing to increased options for independent power production. It will create new high-value products, thereby strengthening the chemical industry in South Africa and contributing to a low carbon/circular economy.

Funding for R&D and early-stage testing will be key to building a diverse pipeline of solutions, with better coordination of existing R&D investments in the water RDI system and a well-resourced new water and sanitation R&D programme. Water sector financing and water pricing will require close scrutiny if there is to be more investment in the sector and more public-private partnerships.

CONCLUSIONS AND KEY POLICY CONSIDERATIONS

South Africa has seen steady growth in scientific research outputs in the Water Security domain, particularly from 2016 onwards. With 6 600 publications, the country is placed 23rd globally. South Africa produced the highest number of publications per GDP and per size of population. The water sector has not geared itself up to make the best use of increasing access to technology, data and associated decision support. This manifests in weakly maintained hydrological monitoring systems, challenges in storing and sharing data, decision making based on outdated data, and an inability to manage complexity as cities grow and resources become more integrated.

Some specific policy considerations are as follows:

- Synergise and harmonise the National Water RDI Roadmap, the National Water and Sanitation Master Plan and the water components of the Industrial Policy Action Plan.
- Ensure improved coordination between all institutions engaged in water research, innovation and solution deployment.
- Support the establishment of co-learning platforms to bring together water researchers, planners, funders, implementers and users.
- Develop a framework that states clearly which parties are involved in or relevant to the water sector and what exactly their roles are.

SECTION III: SYNTHESIS

CHAPTER 12

SYNTHESIS OF OUTPUTS

SUMMARY OF SAForSTI OUTPUTS

The foresight process produced nine STI domains, and a total of 30 STI thrusts as shown in Table 2. Four of the STI domains have three associated thrusts, and four domains have four thrusts. The Future of Society domain has only two STI thrusts, as it is believed that most societal issues are embedded in the other STI thrusts.

Table 2: STI domains and thrusts

STI domain	No.	STI thrust
Circular Economy	CE1	Reducing, Reusing and Recycling Waste
	CE2	Ensuring Sustainable Water, Energy and Food (Agriculture) Security
	CE3	Low-carbon and Climate-resilient Economy
	CE4	Smart Connectivity (Human-machine Interface) and Mobility in Communities
Education	ED1	Skills for the 4th Industrial Revolution
	ED2	Inclusive Innovation and Development
	ED3	Curriculum Development 2030
Energy	EN1	Clean, Affordable and Sustainable Energy for All
	EN2	Renewable Energy Sources and Technologies
	EN3	Energy Efficiency Solutions for Industry and Household Use
	EN4	Distributed Energy Generation and Storage
Future of Society	FS1	Policies and Indicators for STI in a Changing South African Society
	FS2	STI for Inclusive, People-led Development
Health	HE1	Optimisation of Health Systems
	HE2	Improving the Quality of Healthcare
	HE3	Digitisation of Health Systems
High-tech Industry	HT1	Enabling Small Business to Adopt High Tech
	HT3	New Thinking for New Industries
	HT4	New Thinking for Old Industries
ICTs	IT1	Checks and Balances for a Digital Future
	IT2	ICT Infrastructure and Internet Access
	IT3	Big Data, Data Analytics and Decision Support
	IT4	Smart and Sustainable Municipal Service Delivery
Nutrition	NU1	Zero-impact Agriculture
	NU2	Use and Acceptance of Modern Biotechnology
	NU3	Personalised Information for Healthy Nutrition for All
	NU4	Precision and Big Data in Agri-businesses
Water	WA1	Future-oriented Water and Sanitation Solutions
	WA2	Embedding the Water Sector in the 4th Industrial Revolution (4IR)
	WA3	Off-grid and Decentralised Water, Wastewater and Sanitation Solutions

KEY CROSS-CUTTING ISSUES

It is notable that several important issues (e.g. particular technologies, or factors such as climate change) are referenced by more than one thrust, and sometimes by several thrusts. In order to gain a firmer grasp of such issues, where they are explicitly referenced, they have been identified in the thrust abstracts based on a preliminary first-pass analysis. This first-pass identification typically relied on the direct reference to the cross-cutting issue in the thrust proposal outline.

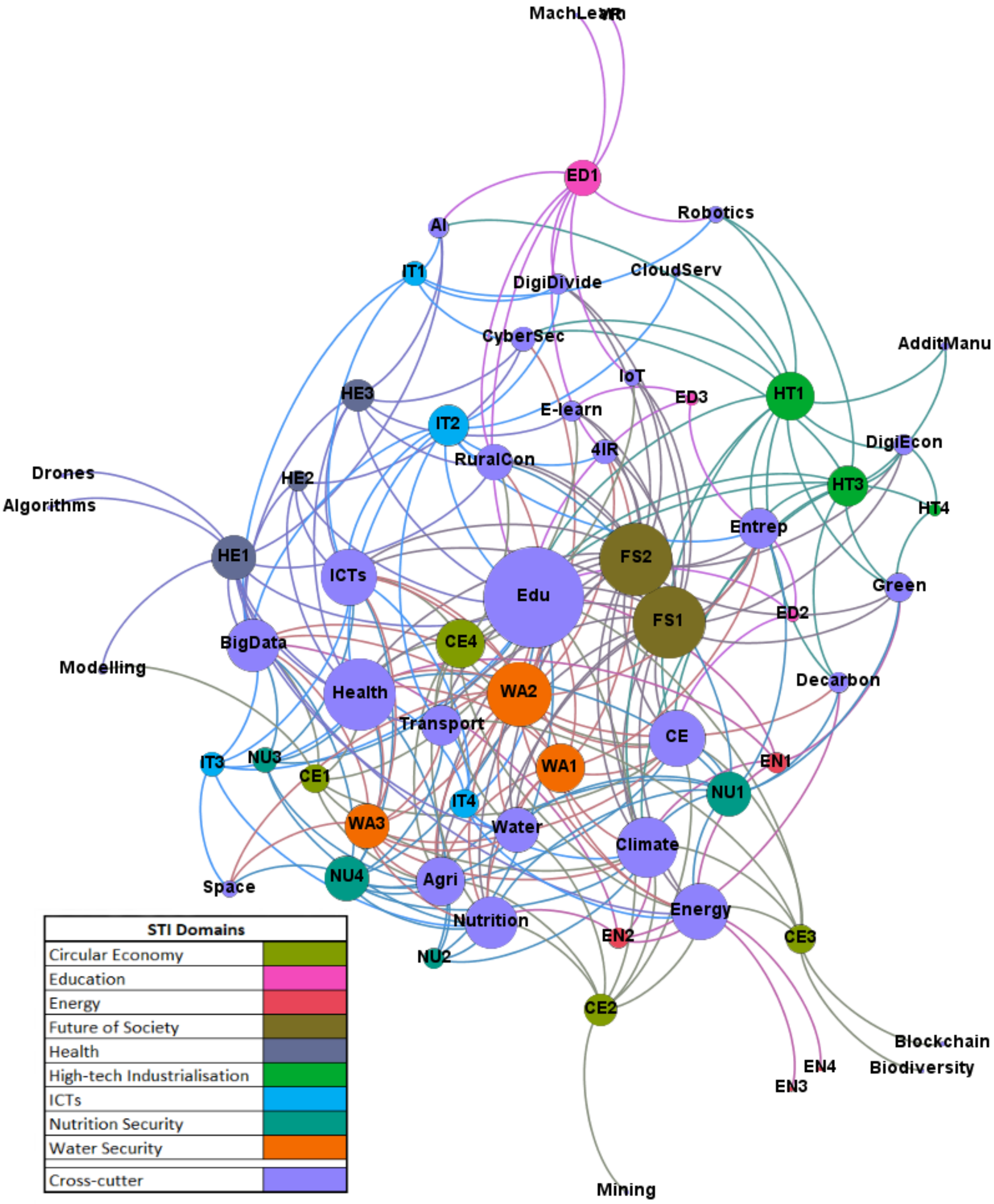

Figure 33: Map of thrusts and cross-cutting issues

Figure 33 presents a consolidated view of these cross-cutting issues. Some of the issues are clearly distinct from others, while there are varying degrees of overlap in others.

There are five cross-cutting issues which link to 10 or more thrusts, namely: education (20 linkages), health (13), climate change (11), big data/big data analytics (10) and energy security (10).

ALIGNMENT TO THE SDGs

To frame the intended results of the STI thrusts in their broader context, and to show their contributions to important societal challenges, they have been mapped to the 17 SDGs, which are listed in Table 3:

Table 3: The UN Sustainable Development Goals

1. End poverty in all its forms everywhere
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3. Ensure healthy lives and promote well-being for all at all ages
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5. Achieve gender equality and empower all women and girls
6. Ensure availability and sustainable management of water and sanitation for all
7. Ensure access to affordable, reliable, sustainable and modern energy for all
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation
10. Reduce inequality within and among countries
11. Make cities and human settlements inclusive, safe, resilient and sustainable
12. Ensure sustainable consumption and production patterns
13. Take urgent action to combat climate change and its impacts
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17. Strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development

The mapping was based primarily on the results of each thrust as formulated in the thrust's proposed outlines, and on the direct linkage between these results and the SDGs. The mapping is shown in Figure 34. As shown, the STI priorities identified are more aligned to the SDG 10 (reduction of inequality within and among countries), followed by SDG 1 (ending of poverty in all its forms everywhere) and SDG 3 (ensuring of healthy lives and promotion of well-being for all at all ages). As predicted, Future of Society's two STI thrusts are part of all the 17 SDGs.

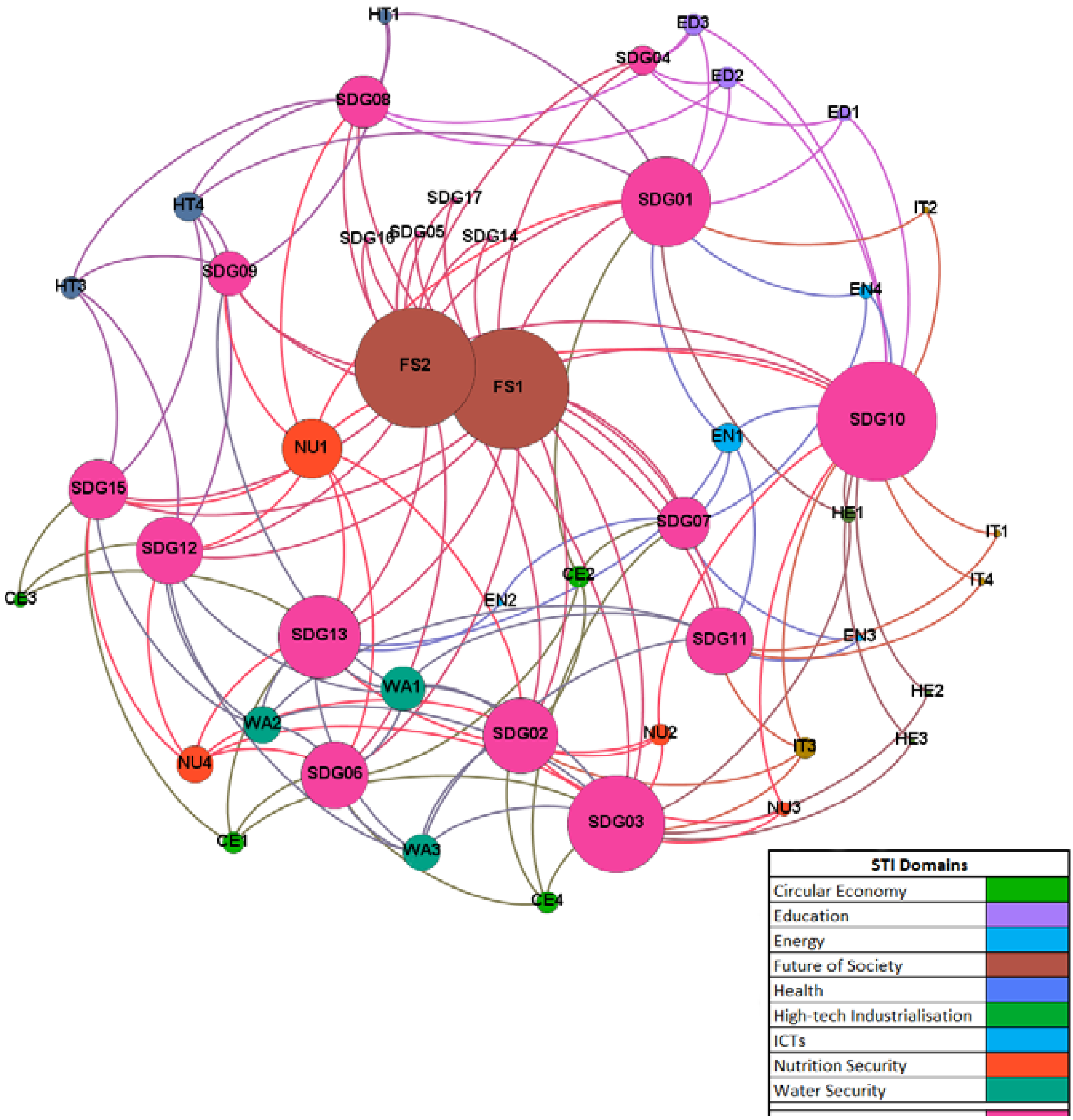

Figure 34: Mapping connections between thrusts and SDGs

SOME RECURRING CONCERNS

A number of overarching concerns emerged across the domains. These, in no particular order, are as follows:

- Climate change
- Water scarcity, security and management.
- Impacts of cybersecurity on individuals and businesses.
- High-cost and uneven ICT infrastructure roll-out.
- Poor nutrition.
- Service delivery challenges.
- Lack of big data skills.
- Lack of availability of data and information, including of big data.
- The management and tracking of pests, diseases and pathogens.
- Energy security.
- Harnessing STI to address societal challenges such as inequality, poverty and unemployment.
- Marginalisation and exclusion of people – as such "science for all" remains a dream.
- Opportunities and threats of 4IR and digitisation.
- Human resource development both as a constraint and a necessity.
- Skills loss and reduced capability to absorb new technology.
- Public safety and morals and their impact on the social fabric and the economy.
- A trust deficit across society.
- Contemporary scientific and technological outputs remain largely focused on promoting disembodied technical solutions, with insufficient attention being paid to either social, political or ecological constraints on their utilisation.

COMMON THREADS

There are many topics that are mentioned or highlighted in multiple domains, sometimes articulated in different ways. Some of the more important of these are elaborated below.

CLIMATE CHANGE

Climate change refers to a significant, long-term change in the expected patterns of average weather in a region. Its impact is and will be wide-ranging, and this may undermine the achievement of the identified priorities in several domains. Thus, the challenge presented by climate change is addressed in many of the domains. For example, an important driver for the Circular Economy domain is the mitigation of the effects of climate change by reducing the current rate of climate change by moving towards a low-carbon economy, to reach a new stable climate state. Furthermore, the circular economy is adapting to the climate change impacts that are now inevitable by building a more resilient economy. In the Nutrition Security domain, research will be needed in drought-resistant crops, production systems, disease, and water and energy management, all aimed at mitigating the effects of climate change.

INCLUSIVE ACCESS TO ICTs

Without improved and inclusive access to connectivity, and the underlying ICT infrastructure as an enabler, many of the proposed priorities for the nine domains cannot be adequately addressed. For example, water security, precision farming, learning that is mediated through new technologies, and the implementation of a national digitised health system, all rely on most citizens having access to ICTs.

The 4IR will demand an educated workforce that is able to deal with the requirements of technology use such as AI, IoT and automation. This requires recently graduated learners to enter the workforce with the requisite skills, and substantial retraining and enhancement of skills for workers already in employment. Skills training on such a large scale will have to be mediated by technology, and this will depend on widespread connectivity and access to such technology.

BIG DATA AND DATA ANALYTICS

Most of the nine domains will require the capability for intensive and extensive use of data and data analysis to achieve the identified objectives. An example is the building of a comprehensive, digitised health system as a basis for achieving a range of objectives, such as remote diagnosis and more reliable epidemiological studies. In addition, the reliance on data generated to monitor a range of activities (e.g. advanced manufacturing processes, patient health record systems, and the data-intensive use of precision farming to improve agricultural productivity and the nutritional quality of crops) will all require big data and data analytics capabilities.

Improved skills in data analytics (greater numbers of people with more in-depth skills) will be needed in most domains, e.g. Water Security, the Circular Economy, Health, High-tech Industrialisation, ICTs, and Nutrition Security.

ENTREPRENEURSHIP

Entrepreneurship is strongly linked to the industrial revolutions of the past, and 4IR is no exception. Entrepreneurship is a primary driver of these revolutions. But more broadly, entrepreneurial activity is the means of sustainably navigating the new paths that must be followed, by individuals and society, in areas as diverse as high-tech industrialisation, ICTs and nutrition security. It is through entrepreneurial success in small-scale but intensive agricultural production facilities that nutrition security will be possible while current levels of poverty and unemployment are reduced. New thinking for old and new industries will require extensive entrepreneurial support to harness the benefits of high-tech industrialisation. Hence the emphasis in the Education domain to embed entrepreneurship across all curricula.

TRANSPORT

The efficient movement of people and goods is an essential characteristic of a well-performing economy. Transport is therefore a ubiquitous factor that needs to be considered across the domains. The distribution of goods, to both urban and rural areas, is relevant for health products (Health domain) and also for agricultural products (Nutrition Security domain). A well-functioning circular economy will entail well-coordinated inter and intra-sectoral transport and logistics linkages. The full benefits of a smart city will be realised provided that smart transport systems form a part of the total smart city solution.

KNOWLEDGE, RESEARCH AND SKILLS

The need for increased knowledge, expertise and human capabilities was noted in many of the thrust proposals. The specifics of the knowledge, expertise and human capabilities required vary to some degree, depending on the domain, although there are also synergies. For example, the Circular Economy domain requires expertise to be built up in water, energy and agricultural technologies, which are relevant to the Water Security, Sustainable Energy and Nutrition Security domains, respectively. In addition, expertise is needed concerning the interaction between these three domains.

A second example is the need for knowledge and expertise concerning social processes and cohesion. This is highlighted in particular for the Circular Economy and the Future of Society domains, but would also be relevant for other domains to facilitate the human-centred deployment of STI to address the social challenges in South Africa more effectively rather than exacerbate them.

A common thread across the domains is therefore the need to build capacity in order to extend the level of expertise in several domains of knowledge, as is envisaged in the Education domain.

Most thrust proposals highlight the need for additional research that is relevant to their domains, although specific areas for research are in general not elaborated on. Institutions with research capabilities should be resourced to undertake the necessary research. This also implies the need for sufficient researchers with the necessary expertise. Where necessary, additional researchers will need to be trained.

COLLABORATION AND PARTNERSHIPS

A strong theme across the thrust proposals is the need for collaboration between institutions and individuals, in a variety of forms. This includes the need for increased collaboration between government departments and science councils, public-private partnerships, international partnerships, and greater interaction with national and global experts, and civil society.

A culture of collaboration and partnership should be actively built so that more may be achieved, more quickly. Where barriers to collaboration exist, or disincentives to cooperate are experienced, these should be addressed and removed as far as possible. In their place, mechanisms that provide incentives for broad collaboration should be implemented.

FUNDING INSTRUMENTS

The availability of sources of funding is another generic resource category that is noted across the 30 thrust proposals. Funding is required for the implementation of all initiatives. While the need for funding is ubiquitous, there may be specific options for sourcing funds that are noted within certain domains, as well as special purpose funding vehicles relevant to a specific domain. For example, a possible means of providing funding for the Energy domain is to redirect some or all of the current fossil fuel subsidies, while in the High-tech Industrialisation domain, financial resources would be needed for experimental development and the commercialisation of technologies.

CONCLUSION

Foresight exercises are undertaken with specific goals in mind, such as to influence policy, to shape strategic planning, or to inform decision-making. The SAForSTI exercise is no exception. It was undertaken, in the first place, to provide an input into the formulation of a decadal plan for the implementation of the 2019 White Paper on STI. However, the results of SAForSTI can have wider application, for instance to strategic planning exercises undertaken by public sector and also by private sector, entities. Moreover, the experience gained through conducting the exercise, and also by STI stakeholders having participated in some of its activities, can contribute to the momentum needed to realise the goals of the White Paper on STI. For example, a valuable by-product of participation in a foresight exercise can be the initiation of networking relationships that transcend traditional boundaries such as those related to sector, discipline or institution. Thus, more creative approaches to the implementation of the White Paper may be fostered by multisectoral and interdisciplinary resources and expertise being more readily mobilised.

There are also lessons to be learned, or observations to be made, in the wake of having undertaken the SAForSTI exercise. Some of these are already evident in the description of the SAForSTI process and its results. A few more may be mentioned:

- On the whole, participation in SAForSTI by STI stakeholders was enthusiastic and substantial. While there is certainly scope to reach even greater levels of participation, the wholehearted involvement of STI stakeholders augers well for future foresight processes.

- The results of reviews and analyses of data relevant to SAForSTI formed key inputs to the exercise, both at its initiation, and at various points during the process. However, more extensive reviews and analyses that could have focused on the early outputs of the process, such as the selected STI domains, would likely have further improved the quality of the final outputs of the process.

- The analysis of the STI domains and thrusts highlighted the importance of having a reliable evaluation of the capacity in South Africa for research and development in different disciplines and in inter-disciplinary areas. Such information facilitates the selection of realistic priorities that are attainable, given the resources available. It also aids in targeting resources to build needed capacity effectively and efficiently.

- Collaboration with international and local partners in the design and implementation of SAForSTI resulted in significant additions to the process and its outputs. An international partner provides an external perspective, apart from potential additional capabilities, which lends credibility to the exercise.

- The 2019 White Paper on STI calls for additional institutional capacity to enable regular foresight exercises to be undertaken, for example, to aid in directing the expansion of the NSI to meet national objectives, and in the formulation of successive decadal plans. The experience of undertaking SAForSTI serves to underscore the benefit of holding regular foresight exercises, so that foresight expertise may be extended and enhanced amongst the STI stakeholder community, resulting in higher-quality results from such exercises.

In conclusion, it is hoped that SAForSTI, by assisting in the development of the first of the decadal plans for the implementation of the 2019 White Paper on STI, will influence the realisation of a better future for South Africa through the application of science, technology and innovation.

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